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MULTIACCESS AND SINGLE CHANNEL VHF RURAL SYSTEMS FOR PUBLIC CALL OFFICES (PCOs) AND TELEPHONE SUBSCRIBERS IN OUTLYING AREAS OF EXCHANGES AND RURAL AREAS

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MULTIACCESS AND SINGLE CHANNEL VHF RURAL SYSTEMS
FOR PUBLIC CALL OFFICES (PCOs) AND TELEPHONE SUBSCRIBERS
IN OUTLYING AREAS OF EXCHANGES AND RURAL AREAS

ABSTRACT

Rural telephony requires the hook-up of telephones in small and widely scattered communities into the main national telephone network. Its main characteristic is the large distances between individual subscribers or Public Call Offices (PCOs), particularly in developing countries where the initial requirement is often for providing only one telephone or PCO in a cluster of villages. Providing acceptable service at economic costs to such rural communities presents special problems.

This paper describes two modern VHF Rural systems which offer for the first time a combination of features essential for successful rural applications, including low investment and recurring costs. These systems enable provision of telephone connections up to a distance of about 50 km at reasonable costs from an existing or a new exchange to provide fully automatic 24-hour service. These systems belong to a new generation and use the latest advances in solid state integrated circuits. The systems are low in costs, extremely reliable, easy to install, flexible in application, require very little power, and can work unattended for long periods. The systems are economical and provide significant advantages over other alternative means of providing communications to scattered rural and other communities. These systems are also useful in rural development, water supply, irrigation, forestry, transportation, electricity and other projects. While the use of VHF systems for meeting communication needs are not new, the older systems lacked many of the above features essential for rural applications.

Telephone services in most developing countries are largely confined to the towns and cities and have not been extended to the small or scattered communities because of the costs and difficulties of implementation of expansion plans. The information given in this paper is topical because of the importance now being attached by the Bank and many developing countries in extending telephone service to rural communities, and should help considerably in speeding up the process.

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CPS
Multiaccess and Single Channel VHF Rural Systems

for Public Call Offices (PCOs) and Telephone Subscribers

in Outlying Areas of Exchanges and Rural Areas 1/

by C.P. Vasudevan 2/

INTRODUCTION

1. Rural telephony requires the hook-up of telephones in small and widely dispersed communities into the main national telephone network. Its main characteristic is the distance between individual subscribers or Public Call Offices (PCOs), and the nearest site where a telephone exchange is or may be conveniently located. Extending telephone service to such areas poses special problems in any country and much more so in developing countries where the initial requirement is often for only one Public Call Office (PCO) in a cluster of villages. In order to extend service to such communities economically special techniques such as the use of modern VHF rural systems are necessary. Two such systems are described in this paper.

2. When landline expansion of the telephone network to outlying areas of an exchange or to remote rural areas is impractical for geographic or economic reasons, the answer is often in the use of recently developed Multiaccess or Single Channel Rural VHF Systems available from a number of manufacturers in different countries. Public Call Offices (PCOs) of subscribers connected via either of these two types of systems get essentially the same facilities as subscribers connected by conventional metallic loops to manual or automatic telephone exchanges. Automatic dialing, subscriber metering, full duplex operations and privacy between subscribers are provided. The two systems share a number of modular components and circuits with mobile radio and other VHF systems in extensive use in industrial countries, and benefit by way of reduced costs possible through large scale production. These systems use the latest solid state integrated circuits to provide high reliability, low power consumption, long component life, minimum maintenance and small space requirements. The latest advances in the design of these systems, and the interfacing provided as an integral part of the systems to

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1/ The information in this paper is largely based on proposals submitted by bidders--four from Japan, one from U.S.A. and one from Finland--in response to a bid invitation in a Bank-financed procurement in 1977. The order was placed with the successful bidders in 1978. The two VHF rural systems described in this paper are also available from manufacturers in other countries.

2/ The author is Telecommunications Adviser, Energy, Water and Telecommunications Department. The opinions expressed in this paper should not necessarily be taken as reflecting the views of the World Bank.
work into telephone exchanges without need for any additional equipment at the exchanges, make these systems attractive for providing PCOs and telephone subscriber facilities at reasonable costs to locations situated as close as 10 km in many instances and clearly attractive for subscribers further away. The systems can economically serve communities up to 50 km on flat terrain (more in favorable terrain or with additional or optional equipment) from exchanges. The systems are also useful in water supply, irrigation, forestry, transport, electricity and rural development systems. In addition, mobile telephone and harbor to ship communication systems are basically similar in system make-up and costs.

3. The Multiaccess VHF Rural system makes efficient use of the radio frequency spectrum by applying standard trunking techniques to use a small group of radio channels to serve a large number of telephone subscribers. Such a system can begin with two radio channels which would typically serve about 10 subscribers. As demand for service increases, the number of radio channels can be increased to eight channels (six in some manufacturers' design) providing service to 60 or more subscribers. The number of subscribers that can be served by a given number of channels depends on the traffic and grade of service desired. The system is flexible and can be engineered to suit individual conditions.

4. The Single Channel VHF Rural system is suitable for providing a single radio trunk (or a few such trunks) between two exchanges or for connecting a limited number of distant telephone subscribers to an exchange. This system can also be engineered to suit individual conditions.

5. Many Bank borrowers are not familiar with the technical arrangements, facilities and costs of these modern systems. This paper furnishes basic information on these two systems.

MULTIACCESS VHF RADIO RURAL SYSTEM

System Description

6. The principal features of this system have been furnished in the introductory section above. Figure 1 attached at the end of this report gives a block diagram showing how up to 60 or more subscribers are served by sharing use of up to 8 base radio units. Figure 2 illustrates how the principal components of the system are connected to one another.

7. This system has three principal component units as shown in Figure 2, namely the Terminal Control Unit (TCU), the Base Radio Terminal Unit (BRTU) and the Subscriber Radio Unit (SRU). The Terminal Control Unit and the Base Radio Terminal Unit are normally installed in the building housing the central telephone exchange to which the rural subscribers are to be connected. These two units may be separated geographically from each other in situations where it is advantageous to install the Base Radio Terminal Unit on top of a hill or to locate this unit closer to the subscribers to be served. The Subscriber
Radio Unit is installed in the rural subscriber premises 1/ or in a nearby place.

8. The Terminal Control Unit provides the interface between the telephone exchange and the Base Radio Terminal to establish (or break down) the necessary connections to connect N exchange lines to M radio channels and vice versa (N > M), to convert/ repeat the signalling between the telephone exchange and the Base Radio Terminal Unit, and to provide for metering of call charges individually for each connected subscriber or PCO. The Terminal Control Unit is connected to the telephone exchange by two-wire (or three-wire) connections on a one-to-one basis for each exchange line assigned to the rural subscribers; and to the Base Radio Terminal Unit by four-wire plus E&M trunks, one for each transceiver (transmitter-receiver) provided in the Base Radio Terminal Unit (BRTU). The Terminal Control Unit (TCU) contains: (i) subscriber modules to provide the interface between the exchange line termination and the TCU, including hybrids to convert 2-wire to 4-wire; (ii) trunk channel modules for the interface between the TCU and the BRTU; (iii) a switching matrix to connect any subscriber line to any trunk and vice versa; (iv) control circuits to establish (and break down) the necessary connections; (v) signalling circuits to provide information to the above control circuits and to convert/repeat the signals between the exchange, the Base Radio Terminal Unit, Subscriber Radio Unit or the telephone; and (vi) power supply equipment.

9. The Base Radio Terminal Unit comprises: (i) up to 8 (as may be required for the total traffic to the radio subscribers) VHF transceivers together with logic, control, and signalling circuits associated individually with each transceiver to work in conjunction with similar circuits in the TCU and in the Subscriber Radio Unit; (ii) power supply equipment; (iii) antenna combiners; and (iv) towers, antenna and feeder cables.

10. The Subscriber Radio Unit comprises: (i) one transceiver unit equipped with up to 8-channel crystal oscillators which can be switched to correspond to each of the receive-and-transmit frequencies of the VHF transceivers at the Base Radio Terminal Unit, (ii) a logic circuit with its associated signalling circuits and (iii) a 17-cycle ringing current generator.

Call Set Up Sequence

11. The setting up (and break down) of a call follows conventional practices except for some additional requirements to establish the correct connection with positive subscriber identification over the radio link and the process of concentration and expansion from N subscriber lines to M radio trunks to N rural subscribers and vice versa where N > M. Further, since the transmitters consume almost all of the power for running the system, one of the objectives is to ensure that as far as possible no transmitter is kept on except for the duration of the call. These functions are controlled by the

1/ In this paper the term "rural" subscriber or PCO is used in a general way and includes any subscriber or PCO in the outlying areas or cities or other locations served by these types of VHF radio systems.
logic signalling and control circuits at the TCU and those associated with each of the transceivers at the BRTU and the SRU. For a call originating from the exchange, the process involves, additionally to the standard sequence, the selection of an idle radio trunk and the establishment of a radio connection with the called Subscriber Radio Unit, and no other SRU. In the reverse direction, for a call originating at the rural end, the calling SRU has to scan over all the channels to connect with an idle transceiver at the BRTU and then establish the connection to the exchange line termination representing the calling subscriber number. To illustrate how the system works, the sequence of events in the setting up of a successful call from a subscriber connected to a central exchange to a rural subscriber connected via the multiple access VHF radio system and vice versa is given in Annex 1 attached to this report.

Other Facilities

12. A second extension telephone can be provided in parallel to the main instruments to provide access to a second user in the same area. For call charging different options are available, e.g. simple call counting, timed charges for local calls and pulse metering of long distance calls or toll ticketing of local/long distance calls.

Traffic Aspects

13. The multiple access VHF rural telephone system can accommodate from as low as 10 subscribers served by 2 radio trunks to as many as 60 to 90 subscribers served by up to 8 radio trunks. All the radio trunks are available for carrying traffic from and to all the rural subscribers connected to the system and thus the available trunk channels are used in the most efficient traffic configuration. The total traffic carrying capacity of the system depends on the number of radio trunks (equalling the number of transceivers in the Base Radio Terminal Unit) and on the grade of service; or expressed in another way, the number of subscribers served by a given number of trunks is related to the average subscriber traffic and the grade of service. A chart showing this is given in Figure 3 at the end of this report. Typically for a 0.05 grade of service and a traffic (outgoing and incoming) averaging 0.05 erlangs per subscriber, 8 subscribers can be served by two trunks, 18 subscribers can be served by 3 trunks, 30 subscribers by 4 trunks, and 90 subscribers by 8 trunks.

Technical Aspects

14. System Features. The equipments generally are all solid state though in one design reed relays and in another some telephone-type relays were used in the TCU. All the units are modular and hence can be arranged flexibly for meeting a variety of different transmitter power outputs (1.5 to 40 watts), number of transceivers (up to 8) at the base station, antenna gains and directivity, signalling arrangements, etc. The power consumption per transceiver in the BRTU or the SRU is about 2.5 watts during idle conditions and 65 watts (with a transmitter output of 10 watts to the antenna system) when carrying conversations— in many situations, the
system can be designed to operate with low power transmitters in the SRU requiring only 10 watts during conversation and to additionally reduce power consumption during idle periods with special logic circuits. These equipments are designed to work off AC mains supplies, with a float charged nominal 12-volt battery (actual working voltage 13.8), or exchange batteries through use of DC-DC static converters. The equipments are compact. For example in one system using all solid state circuits in all the units, a TCU in the base station occupies about 2 feet of rack (19 to 23 inches wide) height and a BRTU with 8 transceivers about 5 feet of rack space including power panels; the SRU at the rural subscriber station is of a size 16.6 x 14.4 x 4.25 inches and can be adapted for rack or wall mounting indoors or pole mounting outdoors. The installation and commissioning of these systems is relatively straightforward and any installer with installation experience of carrier or radio systems should be able to handle the task without difficulty.

15. The system configuration is conventional. Generally the receiver and transmitter of each transceiver at the BRTU and SRU are terminated on a duplexer. At the base station with multiple transceivers, antenna combiners are used to connect up to 4 transceivers via a low loss feeder cable to an antenna, a second antenna being used where the BRTU has more than 4 transceivers. These antenna combiners have a loss of 3.3 dB for combining 2 transceivers and 6.6 dB for combining 4 transceivers. At the SRU where only one transceiver is involved the duplexer directly connects with the antenna via the feeder coaxial cable.

16. The equipment units are built for trouble-free operation and easy maintenance. For example, the SRUs located in scattered rural areas are expected to have a mean time between failures (MTBF) of about 4 years. When these units go faulty, the repair generally is in the form of replacing the faulty card which can be done in situ or at the base station—the repairs of the faulty cards being done in a central location. Thus any technician now looking after carrier systems should be adequate for restoring communication. The principal maintenance effort is to keep the batteries in good condition and can be handled by persons with minimal training.

17. Frequency requirements: The VHF transceivers in the Multiaccess Rural system operate in the 146-174 MHz band. The frequencies of transmitters (and similarly the receivers) in a system should be spaced a minimum of 25 KHz from each other. Further the transmitter and the receiver frequencies in any system should be not less than 4.5 MHz and not more than 7 MHz apart—the lower figure being necessary to keep down the cost and complexity of the duplexers and the latter to keep the frequencies within the bandwidth of the antenna. A fully equipped Multiaccess system requires 8 pairs of frequencies. Since these frequencies can be reused in areas not subject to interference from the system, only about 6 to 8 sets (each with 8 pairs) of such frequencies are required for the operation of a large number of such systems to cover even a large country. The frequency requirements thus claim only a small part of the total available frequency band and the individual assignments permit considerable flexibility to fit local conditions.
18. The performance of the system is defined in terms of weighted signal to noise ratio on the circuit for more than a percentage of the time (reliability). Usually a figure of 50 db signal to noise ratio met for 99.9% of the time is prescribed for junction circuits while a lower figure of 45 db is considered satisfactory for a subscriber radio circuit as in this system.

19. The maximum distance coverage of the system for a specified performance depends on the system features and transmission losses and is given by the formula $M - At$ where $M$ is the system figure of merit and $At$ is the total propagation loss (including fading allowance for the required degree of reliability). The system figure of merit depends on the transmitter power, the receiver noise figure, weighted bandwidth improvement by the modulation system and emphasis signal weighting. The transmitters come with different outputs and the receiver noise figure is a design feature of the particular equipment. The other factors are usually prescribed in the specification and remain the same for all manufacturers. The transmission loss between the transmitter output and the receiver input consists of the free space radio propagation loss between isotropic antennae, gains of the transmitting and receiving antennae, losses in feeder and channel network (duplexer and antenna combiner), fading margin for the required reliability and additional propagation losses caused by obstruction, reflections or passive repeaters in the radio path. A fuller treatment of these factors affecting noise performance and system design is given in "Economic and Technical Aspects of the Choice of Transmission Systems" published by International Telecommunications Union, CCIR and other publications.

20. The system engineer has a wide range of options—choice of transmitter power, antenna gain, feeder losses, system configuration to reduce combiner losses, etc.—to attain the prescribed noise objectives at the lowest cost. Transmitters are generally available in power outputs from 1.5 watts to 40 watts, base antennae with omnidirectional radiation pattern with gains from 3 dbi for a Brown antenna to 8 dbi for a four-stack array (directional antennae have higher gains and can be used where suitable), Yagi antennae for Subscriber Radio Units from 7.5 to 16 dbi gain, feeder cable losses at 150 MHz ranging from 1.5 db to 9 db per 100 meter length, etc.

21. The performance of a typical system is given below to illustrate the general distance coverage that can be realized with different options. This system employs a transmitter output of 10 watts, a four-stack array antenna (gain 8 dbi) mounted 50 m above ground, a subscriber antenna mounted 25 m above ground, feeder losses at the transmitter and receiver totalling 4 db, a duplexer loss of 1 db at each transceiver and an antenna combiner (combining four transceivers) loss at 6.6 db. Assuming a smooth plane earth with no obstruction and reliability figures based on Raleigh distribution fading, the path losses and distance coverage for a weighted 45 db signal to noise ratio with 99.9% reliability (also for a weighted 50 db signal to noise ratio with a 90% reliability) are given below for different gains of Yagi antennae at the Subscriber Radio Unit.
Table 1

<table>
<thead>
<tr>
<th>Subscriber Radio Antenna Gain (dbi)</th>
<th>Maximum Path Loss (db)</th>
<th>Distance Coverage (Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>118.9</td>
<td>36.3</td>
</tr>
<tr>
<td>10.6</td>
<td>121.4</td>
<td>42.6</td>
</tr>
<tr>
<td>13.2</td>
<td>124.0</td>
<td>49.1</td>
</tr>
<tr>
<td>15.8</td>
<td>126.6</td>
<td>53.4</td>
</tr>
</tbody>
</table>

Instead of using higher gain antennae to get a greater range, it is also possible to use feeders with lower losses, transmitters with higher power or towers of greater heights (to reduce propagation losses other than free-space loss) etc., or a suitable combination of one or more of these options.

Prices

22. The cost information for the Multiaccess and Single Channel VHF Rural systems in the subsequent paragraphs in this paper are largely based on the offers received in response to a bid invitation in a Bank financed procurement (see footnote at bottom of page 1).

23. The total prices offered by the different bidders varied considerably—two low bids were within 10% of each other; two other bids were about 50% higher; two others 70% higher; and one 125% higher. The prices of individual components also varied from one to the other. The more modern systems employing solid state technologies were lower priced as compared with those offering older type equipments. The following prices are taken from the two low bids as representing the costs likely in future projects. It is likely that the cost of component parts in these equipments will show a decreasing trend due to continuing trends in large scale integration technology and will offset the increasing cost trend for labor. Hence, prices should be stable in current dollars over the next 5 years or more. A contingency provision of about 10% or 20% should be adequate to cover price variations in individual bids for reasonably sized orders.

24. The total installed price of a base station (Terminal Control Unit, Base Radio Terminal Unit including the transceivers, antenna combiner, feeder antenna, tower and power plant) and that of a Subscriber Radio Unit (including the antenna, tower, power plant and telephone), are given below.

Table 2

<table>
<thead>
<tr>
<th>Base station equipped with 2 radio channels 1/</th>
<th>US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot; &quot; &quot; 3 &quot; &quot;</td>
<td>16,000</td>
</tr>
<tr>
<td>&quot; &quot; &quot; 4 &quot; &quot;</td>
<td>18,500</td>
</tr>
<tr>
<td>&quot; &quot; &quot; 6 &quot; &quot;</td>
<td>21,000</td>
</tr>
<tr>
<td>&quot; &quot; &quot; 8 &quot; &quot;</td>
<td>25,000</td>
</tr>
<tr>
<td>Remote Subscriber Radio Station, each</td>
<td>30,000</td>
</tr>
</tbody>
</table>

1/ Base station equipments comprise TCU and BRTU.
25. **Financial viability:** Based on the investment costs and the traffic handling capacity (dependent on the number of channels in the base station), the annual costs (including an 8% return on capital) have been worked out for different system sizes with varying numbers of radio channels and of rural subscribers served. From this, the cost per call as well as the average number of calls per subscriber per day has been calculated and is given below:

<table>
<thead>
<tr>
<th>System Configuration</th>
<th>Capital Investment</th>
<th>Annual Cost</th>
<th>Call Capacity Per Year</th>
<th>Average calls /sub/day</th>
<th>Cost per call US cents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/10</td>
<td>43,500</td>
<td>10,005</td>
<td>26,250</td>
<td>10.5</td>
<td>38</td>
</tr>
<tr>
<td>3/15</td>
<td>56,000</td>
<td>12,880</td>
<td>26,250</td>
<td>7.0</td>
<td>49</td>
</tr>
<tr>
<td>4/15</td>
<td>58,500</td>
<td>13,455</td>
<td>43,320</td>
<td>11.5</td>
<td>31</td>
</tr>
<tr>
<td>4/20</td>
<td>71,000</td>
<td>16,330</td>
<td>43,320</td>
<td>8.7</td>
<td>38</td>
</tr>
<tr>
<td>4/30</td>
<td>96,000</td>
<td>22,080</td>
<td>43,320</td>
<td>5.8</td>
<td>51</td>
</tr>
<tr>
<td>8/30</td>
<td>105,000</td>
<td>24,150</td>
<td>135,000</td>
<td>18.0</td>
<td>18</td>
</tr>
<tr>
<td>8/40</td>
<td>130,000</td>
<td>29,900</td>
<td>135,000</td>
<td>13.5</td>
<td>22</td>
</tr>
<tr>
<td>8/50</td>
<td>155,000</td>
<td>35,650</td>
<td>135,000</td>
<td>10.8</td>
<td>26</td>
</tr>
<tr>
<td>8/60</td>
<td>180,000</td>
<td>41,400</td>
<td>135,000</td>
<td>9.0</td>
<td>31</td>
</tr>
</tbody>
</table>

**Notes:**
- **Column 1:** first figure is number of radio channels and the second the number of rural subscribers served.
- **Column 2:** capital investment in U.S. dollars on prices in para. 21.
- **Column 3:** annual costs in US dollars are based on maintenance of 5%, depreciation 10%, and financial return 8% on capital, totalling 23% of investment.
- **Column 4:** call capacity figures are based on a grade of service of .05 during the busy hour, holding time of 3.5 minutes for call, 7 times busy hour traffic in a day and 250 days in a year. On this basis, one erlang of traffic (or 36 HCS) in the busy hour will be equivalent to a capacity of 30,000 calls per year.
- **Column 5:** column 4 divided by 250 days divided by number of subscribers.
- **Column 6:** column 3 divided by column 4.

26. The above table assumes that the traffic capacity of the different systems are fully utilized and indicates that call charges to be recovered for achieving an 8% return on invested capital for systems with different numbers of radio channels and subscribers. As would be expected, a system with 8 channels (the maximum) is the most traffic and cost efficient; and, further, for a system with a given number of radio channels (or traffic capacity), the costs per call are less when subscribers with high traffic
are connected to the system, i.e., fewer connected subscribers able to utilize the traffic capacity. Even so, the incremental cost ($2,500) and annual recurring charges ($600) of connecting an additional subscriber to the Multiaccess system are modest and allow light traffic subscribers or PCOs to be provided economically over distances of up to 50 km. These costs are based on connecting one telephone subscriber or PCO to an SRU. The unit costs will be lower if the SRU is shared with one or more nearby subscribers.

27. Local Manufacture—Savings in Foreign Costs. The assembly of VHF transceivers and associated logic circuits and power units are similar to the assembly of radio TV receivers and other electronic units now being done in many developing countries. Where the annual demand for VHF radio systems runs into hundreds, as would be the case in medium and large-sized countries with plans for extending communications to rural areas, the assembly of these systems under license should present no problems, prove economical and save foreign exchange. The fabrication of Yagi antennae and steel towers should present no difficulties even in small countries. The feeder coaxial cables and accessories can be procured in bulk directly from cable manufacturers (and similar antennae, if not fabricated locally) with consequent savings in costs. Thus the foreign currency requirements can be reduced significantly in many countries deciding to use these or other similar systems extensively.

SINGLE CHANNEL VHF RADIO RURAL SYSTEM

28. This system is simpler and less sophisticated than the Multiaccess VHF Radio rural system and provides the same facilities to a subscriber (or PCO) connected to an automatic or manual exchange via this system as a subscriber connected via a metallic pair or a Multiaccess VHF system. Alternatively, the system can provide a junction circuit between two exchanges. A pair of terminal equipment and antennae, one at the exchange and the other at the subscriber end (or at the other exchange), are required on a dedicated basis for each subscriber connection (or junction). Further, each circuit provision requires one pair of VHF frequencies.

29. Each radio terminal consists of a Transmitter Receiver (transceiver) Unit, a power supply unit and a logic circuit whose main function is to serve as an interface to repeat the signals from the exchange to the subscriber (or the other exchange) and vice versa, and to switch on the transmitter unit only for the duration of a call to conserve power. Since the number of radio channels is the same as the number of subscribers, no Telephone Control Unit as in a Multiaccess System is required; similarly, since each radio terminal is connected to its own antenna, no antenna combiner unit is required either.

30. The radio terminals contain hybrids to convert from 2-wire to 4-wire and vice versa. The logic circuits at the terminals can provide by strapping (or through use of plug in circuit cards) different signalling interface options. For a subscriber connection to an automatic exchange, the radio
terminals at the two ends are connected by 2-wire circuits to the line termination at the exchange and the subscriber telephone. The system uses a 3825 Hz out of band E&M signalling over the radio path. The E&M wires relay the onhook and offhook conditions of the subscriber to the exchange via the logic circuits at the two terminal equipments. In addition, the logic circuits of the radio terminal at the exchange end, on receiving the 17 Hz ringing from the exchange, apply an earth on the E signalling wire which activates a ringer at the receiver radio terminal to call the subscriber. In the reverse direction, the logic circuits repeat the dialing pulses from the subscriber to the exchange. Other strapping options permit connections to a manual exchange or provide a junction between manual or automatic exchanges. Thus this system provides the same facilities as a carrier channel but with the additional built-in logic circuits (instead of special relay sets) to interface with the exchange and/or the subscriber at the two ends.

31. The radio terminals including the logic circuits are all solid state and the terminals are of modular construction for providing different power outputs or signalling arrangements. The component units are standard circuit cards used in other systems, e.g., Multiaccess VHF rural systems, mobile radio systems, etc. The power supply is from a nominal 12-volt float charged battery (13.8 volts actual), but AC mains supplies or other DC voltage sources, e.g., exchange batteries, can also be used with DC to DC converters. The power consumption is less than a watt per terminal under standby conditions and about 12 watts per terminal for the duration of the call for an RF power output of 1.5 watts and about 60 watts for an RF power output of 10 watts. Each terminal measures about 15" x 17" x 4.5" and can be used indoors or outdoors with rack, wall, or pole mounting. An additional feature is the possibility of connecting up to 5 party line extension telephones to the rural radio terminal with coded ringing to differentiate between subscriber instruments. Different types of metering arrangements can be provided. The equipment reliability and maintenance features are similar to those of an SRU of the Multiaccess system—see para. 16.

32. The radio terminals are designed to operate in any frequency in the 146-174 MHz band and require two frequencies, one for each direction for each connected subscriber or junction circuit. As in the case of the Multiaccess system these frequencies should be not less than 4.5 MHz and not more than 7 MHz apart. These frequencies can be reused elsewhere in the country beyond the interference range of the system.

33. The distance that can be spanned satisfactorily depends on the factors which have been dealt within the paragraphs on this subject earlier for the Multiaccess VHF systems. However, the transmission losses for the single channel systems are lower by about 6.6 db as compared with a Multiaccess system of 4 or more channels because of the elimination of the antenna combiners. Further, being a single channel system, a low-cost high-gain Yagi antenna can be used with the exchange and radio terminal also. As a result lower transmitter powers with economies in battery power supplies become feasible as compared with the Multiaccess system.
34. The costs of a typical single channel VHF rural radio system (10 watts RF power output, 5-element Yagi antenna including average costs of towers) would be about US$4,500 for the two terminals including installation and to annual costs of about $1,050 comprising depreciation 10%, maintenance 5%, and return on capital 8% (totalling 23%). These unit costs are based on use of a VHF system exclusively for one subscriber and will be reduced if the circuit is shared on a party line basis to serve up to six subscribers who may be within a few kilometers of the distant terminal.

SCOPE FOR APPLICATION OF THE TWO SYSTEMS

35. The major characteristic of rural telephony is the large distances between the individual subscribers (or PCOs) and the nearest site where a terminal telephone exchange is (or may conveniently be) located. The distances may be one to several orders of magnitude longer than the average length of subscriber connections in an urban or suburban area. The principal objective of rural telephony is to connect these widely dispersed telephones to an existing or new telephone exchange, namely to provide a least-cost distribution network covering these rural telephones.

36. Wire and radio based systems for such distribution can be considered in a general way as alternatives for meeting the rural telephony requirements. Local conditions and actual kind of applications determine which system is preferable—of the many factors, the most important is that of low investment and recurring costs because of the limited financial resources and the need to keep subsidies, if any, to a minimum. A brief outline regarding the scope of application of the various systems is given below; a more detailed analysis comparing these systems is given in Annex 2.

37. In terms of a least-cost solution, the choice between wire and radio based system alternatives (or the need to use both in combination) very largely depends on the telephone density, viz., number of telephones per square kilometer—higher density areas generally favor use of wire-based systems, viz. connecting subscribers to an existing or to a new exchange using usually open wire for distribution, while lower densities favor the use of radio systems. Though a decision can be made only after a case-by-case study, generally the break-even point for wire-based systems, with use of multiplex where advantageous, is when the average subscriber distance is below about 10 km for connections to an existing exchange or as low as 4 km if a new exchange has also to be provided for.

38. The radio systems useful for connecting rural subscribers to an exchange are the Multiaccess and Single Channel VHF systems described in this paper, two other Multiaccess systems working in the UHF and microwave bands, a satellite system and an HF system. Of these, one or the other of the two VHF systems is lower in cost than other radio systems and have the best

1/ See para. 22.
combination of all the other features essential for successful rural application. Hence, one of these two systems is likely to be the system of choice from the economic and other points of view for most rural applications, where the need is for providing one (or a few) telephones in many small and dispersed communities.

39. Other radio systems provide optimal solutions in special circumstances and are dealt with in Annex 2. Briefly:

(a) The Multiaccess UHF and microwave, particularly the latter, are more expensive and have less service range (and area) for given mast heights than Multiaccess VHF systems while providing essentially the same features. 1/ However, VHF frequencies are crowded in many countries though this situation is unlikely in developing countries in early stages of development. The UHF and microwave systems in that order are useful if VHF frequencies become unavailable.

(b) The satellite systems only for rural telephony purposes are considerably more expensive (by 10 to 100 times) than VHF systems. The application of these systems is when communities are very distant from the national telephone network or lie across large areas of difficult terrain, e.g. across deserts or seas.

(c) HF systems are in widespread use in rural telephony since they can provide service to distant or isolated communities often 100 km or 200 km from the national networks. Further, HF systems can provide service to locations where VHF, UHF or microwave systems are likely to be technically inappropriate or expensive. However, HF systems have a number of disadvantages, viz. low traffic capacity, low reliability, require attention, etc. For these reasons, the use of HF systems is advantageous only when a low quality communication with minimum traffic capacity is to be provided to locations which cannot easily or economically be served by VHF systems.

1/ For applications in rural areas (or for light spur routes) VHF and UHF systems in that order have advantages of lower costs and greater service range (and area) with given mast heights than microwave systems for the following reasons: good propagation characteristics, viz. low losses with no deep selective fading; small fading margin requirements without loss in system reliability; simple lightweight antennas with low wind resistance, e.g., Yagis, dipole arrays or helical antennas; moderate mast heights because Fresnel or line of sight clearance is not mandatory and are usually not required on short hops; reduced cost of towers because no special rigidity requirements are imposed; no need for expensive and frequency dependent microwave components, e.g., RF filters, circulators or wave guides; simple installation with flexible coaxial cable; and high transmitter output at moderate cost.
40. The choice between the Multiaccess and Single Channel VHF rural systems depends largely on availability of frequencies and costs. VHF frequencies in the 146-174 band are widely used for a number of services and it is important that the limited number of available frequencies are efficiently used. From this point of view, the Multiaccess system is clearly to be preferred, though this factor may not be significant where only a few subscribers have to be provided from an exchange or where the pressure on frequencies is not heavy as is likely in many developing countries. From the cost point of view, a Multiaccess system will be more economical when more than about eight subscribers are to be connected. The Multiaccess system is flexible from the traffic point of view and permits efficient use of the facilities for connecting heavy and light traffic subscribers—the heavy traffic subscribers can be provided economically with more than one Subscriber Radio Unit to prevent subscriber busy conditions, and the incremental cost for connecting light traffic subscribers is less than with single channel systems. Thus the use of single channel systems is limited to applications where the subscribers to be connected to an exchange are only a few. In all other cases the Multiaccess VHF system is to be preferred.

41. In conclusion, with the availability of modern VHF systems dealt with in this paper, the likely choice for serving small dispersed rural communities in developing countries, particularly in the early stages of development, will largely be between Multiaccess VHF and Single Channel VHF systems as explained in para. 40. In some cases where a number of potential telephone subscribers are near an existing exchange or clustered close to a possible new exchange, traditional wire-based systems may prove to be the preferred solution. Even so, the other radio systems are useful in special situations (para. 39). In many cases the best solution is through use of a combination of the above systems. The low cost and the other attractive features of the two modern VHF systems eliminate many of the disabilities and limitations of the other systems thereby making feasible the extension of telephone service to rural areas at lower costs and better quality than ever before.
Multiaccess VHF Rural System

Call Set-Up Sequence and Power Conservation

1. This annex deals with two special features in the Multiaccess system relating to (a) the sequence of events in the setting up of calls from the exchange to a subscriber connected via the Multiaccess system and vice versa and (b) arrangements for ensuring ready availability of radio trunks while minimizing power consumption to conserve battery supplies, particularly at the subscriber terminals.

Call Set-Up Sequence

2. A description of the block schematic and interrelationship of the units making up the system is made in paragraphs 5-10 and Figures 1 and 2 of the main text. The description below illustrates the principal steps in the call set-up process and deals broadly with the subject. The steps are different for calls originating at the exchange for the remote rural subscriber and vice versa.

3. Calls originating at the exchange: When a subscriber connected to the exchange dials the number of a rural subscriber, the sequence of events in the call set-up process is as follows:

(a) The exchange sends out ringing current on the called line, which is received and recognized at the individual line circuit in the Terminal Control Unit (TCU) corresponding to the called number.

(b) The TCU extends the called line circuit to an idle VHF transceiver in the Base Radio Terminal Unit (BRTU) via the switching matrix and the trunk control circuits in the TCU.

(c) The selected transceiver sends out a call signal which includes the identifying number of the rural Subscriber Radio Unit, which has a one-to-one correspondence with the called number.

(d) The receivers in all the rural Subscriber Radio Units first lock on to the frequencies of the calling transceiver in the BRTU and receive and analyze the signal—please see the second part of this annex on how this is done; the specific Subscriber Radio Unit for which the call is intended recognizes that it is called and acknowledges the same by sending back to the Base Radio Terminal its own number.

(e) The transceiver at the BRTU then transmits a continuous signal to ensure that all other SRUs stay away from this channel for the duration of the call; and then a signal is sent to the called Radio Subscriber Unit to have a ringing current sent to the called subscriber telephone.

(f) When the called subscriber answers by lifting his handset off the hook, the call is established.
4. Calls originating from the subscriber: For a call originating from the rural subscriber, the sequence of events is as follows:

(a) When a rural subscriber lifts his handset, its parent SRU finds an idle channel—two methods for doing so while conserving power are given in the second part of this annex—and sends a calling signal.

(b) When this signal is received in the corresponding transceiver of the BRTU at the base station, this channel is busied so that calls from the SRUs or exchange lines stay away from that channel for the duration of the call. The transceiver also sends an acknowledgement signal to the calling SRU.

(c) The Subscriber Radio Unit then sends its identifying number—which has a one-to-one relationship with the directory number of the subscriber—to the BRTU which in turn transmits this number to the trunk control circuits in the TCU.

(d) The TCU extends the trunk via the switching matrix to the particular line circuit at the TCU corresponding to the calling subscriber number and thereby to the calling subscriber line termination at the exchange.

(e) When the calling line seizes a free register at the exchange, the latter returns a dial tone to the rural subscriber.

(f) The rural subscriber dials the number of the called number which is repeated to the exchange via the radio terminals and the TCU.

(g) The exchange then sets up the connection and activates the metering or call-charging arrangements.

The additional time required to complete the above operations over the time for setting-up a call or from a conventional subscriber is less than 3 seconds.

Idle Channel Selection and Power Conservation

5. The following paragraphs describe broadly two methods used for minimizing power consumption at both the base station and the rural Subscriber Radio Terminal. Recognizing that the VHF transmitters at the two ends consume most of the power used in the terminals, the method used to minimize the power consumption is to switch-off all transmitters not required for the setting-up of a call or for the duration of the conversation.
6. Basically two methods are employed. In both methods, all the VHF receivers at both the base station and the Subscriber Radio Units are always in the on-position, ready at all times to receive a signal. Similarly in both methods, the VHF transmitters at all the Subscriber Radio Units are in the off-position except when required to set-up the call or for the duration of the conversation. The difference between the two methods is that in the first one the idle transmitter at the base station is kept on while in the second all idle transmitters are switched-off. The operational steps in the two methods to make available a radio channel when required for a call is also different. These are described below.

7. Method 1. As stated above, apart from the channels which are occupied for setting-up a call or for conversations, one idle transmitter in the BRTU at the base station is kept on, while all the receivers at the BRTU and the receivers in all the SRUs—but not the idle transmitters in the SRUs—are also on. This transmitter at the BRTU transmits a special signal. The receivers in all the SRUs not busy on calls continuously scan in sequence all the 8 (or less) frequencies used in the Multiaccess system until the special signal from the BRTU is received. At this point all the idle SRUs stop scanning and stay on this frequency, ready to respond to a call signal from either end. This channel, called the marked channel, is the one to be seized for the next call originating from either end (see paras. 3 and 4 above). When this channel is seized for setting-up a call, two events take place; firstly the called or calling SRU switches on its transmitters thus activating the channel in both directions enabling the call to progress, and secondly to start the process for getting another marked channel ready to receive fresh calls.

8. Method 2. In the second method, all the idle transmitters in the BRTU and SRUs are in the "off" position and are switched on only when required, while all the receivers are always in the "on" position. The receivers at all the Idle Subscriber Radio Units continuously scan through the 8 (or less) frequencies of the Base Radio Terminal transmitters. When a call originates from the exchange for the rural subscribers, an idle transmitter at the Base Radio Terminal is switched on and sends the called subscribers' identifying number. When any of the Subscriber Radio Units receive this signal, they pause on this frequency. The specific called Subscriber Unit recognizes the call and locks on to the channel by sending its own identification number for an acknowledgement. The other Subscriber Radio Units continue with the scanning process. For calls originating at the rural end, the receiver at the SRU scans through the 8 frequencies and locks on an idle frequency, switches on the transmitter and sends the calling and identification number. The corresponding receiver at the Base Radio Terminal switches on its transmitter and acknowledges the call signal and establishes the connection to the exchange which in turn sends the dial tone to the rural subscriber.
Comparison of the Two VHF Radio Systems with 
Alternative Methods for Providing Rural Service

1. This annex reviews briefly the various alternatives available for providing rural telephone service and how the two VHF Rural radio systems described in this paper compare with the other alternatives.

Comparison Between Wireline and Radio Systems

2. The principal requirement of rural telephony is to hook up telephones in small and widely dispersed communities to the national telephone network. The systems that are generally useful for doing so are:

(a) the use of wire-based systems; viz., connecting the rural subscribers (and PCOs) to an existing exchange or to a new exchange using usually open wires (with or without use of multiplexing); if to a new exchange, it is to be linked in addition to an existing exchange in the national network;

(b) use of radio systems; apart from the VHF rural systems described in this paper, other alternatives are VHF and microwave multiaccess rural systems, satellite communication and HF radio systems.

The choice of the most appropriate system has to be made on each individual situation and depends on investment and recurring costs, traffic pattern, terrain, reliability and ease of maintenance, etc. Of these, the cost aspect has the strongest influence in deciding on the optimal system (or a combination of systems) in any given application, since the extension of service to rural areas in developing countries is limited by the availability of investment funds and the need to keep the operational subsidies as low as possible. Complete economic comparison between different systems can be made only on a case-by-case basis. To keep the discussion simple without sacrificing the essentials, the economic and other features of the alternative systems are compared with those of the VHF rural systems which basically have the most desirable combination of features for rural applications and are likely to emerge as the system of choice for providing initial telephone service to widely dispersed rural communities in developing countries. Even so, the other alternatives have advantages which make them either alone or in combination with other systems the optimal choice in specific applications.

Wire vs. Radio-Based Systems

3. The Multiaccess VHF systems—also the Multiaccess UHF and microwave systems—connect subscribers or PCOs scattered over an area of about 5000 sq. km. (equal to the service area of 20 or more rural exchanges) directly to the Base Radio station which is ordinarily located with (or linked to) the Terminal Control Unit in an existing exchange. The satellite and HF systems can span much larger distances and can extend the service areas of exchange even more than VHF systems.
The cost of connecting a subscriber within the service area of these radio systems to the exchange is relatively independent of the distance. Where the terrain is difficult as in mountainous territory or across rivers, the radio systems are generally the only feasible way for providing service.

4. In wire-based systems, the rural subscribers are either connected directly to an existing exchange or to new exchanges which will be linked with the national network. The cost of connecting the subscribers in either case depends largely on the average distance of the subscribers to the existing or new exchanges—in the latter case the additional costs of the new exchanges and the links to the national network also become relevant.

5. Compared with Multiaccess VHF Radio systems, the use of wire lines (with multiplex, where advantageous) for connecting several subscribers to an existing exchange is likely to be more economical where the average distance of the subscribers to the exchange is less than about 10 km. Where these subscribers are to be connected to a new exchange, the comparison is somewhat more complex and depends both on the size of the exchange (the more the number of lines the cheaper per line costs and particularly so in the small sizes used in rural areas) and on the service area (the larger the service area, the more the unit costs of distribution). Generally speaking, the installation of a new exchange and the use of wire line distribution for connecting subscribers is likely to be more economical than through use of Multiaccess VHF systems where a cluster of subscribers are located in a relatively small area, e.g. about 20 subscribers within an area of 100 sq. km. or 100 subscribers in an area of 400 sq. km.

6. In developing countries, the subscriber densities (number per sq. km.) in rural areas, particularly in the early stages of development, are likely to be 50 to 100 times lower than in similar areas in industrial countries. Because of these generally low telephone densities, the use of wire-based systems is likely to be justified economically only for connecting subscribers in the smaller towns; and one or the other of the two VHF rural systems is likely to prove economical for serving most rural areas, where the need is to provide one (or a few) telephones in each of many small and dispersed communities.

Comparison of VHF Rural Systems With Other Radio Systems

7. The Multiaccess UHF and microwave systems provide basically the same facilities as the Multiaccess VHF systems.1/ The principal advantage of these UHF and microwave systems is that they operate in frequency bands where the availability of frequencies is freer—particularly important in many

1/ The Multiaccess microwave system uses digital multiplexing and has 15 radio channels. Thus its traffic handling capacity is more than double that of a fully equipped Multiaccess VHF system. This factor is not generally relevant to rural telephony in developing countries. This system is manufactured at present in only one country.
industrial but not in developing countries. However, the cost of radio equipments operating in these higher frequencies is higher by 20% to 80% than those for the VHF band. Further, the transmission losses in these higher frequency bands, and particularly in the microwave band, are greater than at VHF frequencies because of the higher free space loss and higher fading margin required, resulting in a reduction of the service area. The towers, feeders and antennas are less expensive in the VHF and UHF band as compared with those for microwave systems, and in addition are easier to install. Hence, the Multiaccess UHF and microwave systems are to be considered only when frequencies in the VHF systems are not available.

8. Satellite systems provide high quality circuits as in the above radio systems, though the pronounced delay inherent in these circuits has a somewhat undesirable effect on conversations. The principal advantage of these systems is that they can span very long distances and link any point in the country to any other. While this feature is very important for connecting PCOs or subscribers in remote or inaccessible locations, e.g. across deserts or seas, it is not important for ordinary rural communication where the community of interest of the rural subscriber is largely to the nearest market or district town. The principal disadvantage of the system is that the provision of one or a few circuits to a rural community is likely to cost at least 10 to 20 times more than with the VHF systems, based on optimistic estimates of current costs and considerably higher on the basis of conservative estimates.

9. HF systems are in widespread use for providing service in rural areas of many developing countries. The advantages are that the distance range of these systems is much higher (100 to 200 km. is easily spanned with reasonable power, say 100 W transceivers) than is possible with single hop VHF, UHF or microwave systems. Further, HF systems can be effectively deployed to provide service in any terrain including some kinds of mountainous terrain where VHF and other systems are not feasible. However, HF systems have a number of disadvantages. The circuit availability is poor and is only about 70% to 80% in the simpler rural systems, as compared with over 99% for the other radio systems. The operating frequencies have to be changed for day and night working and also to avoid interference signals, thus requiring operators with some knowledge of propagation conditions. The power requirements are considerably higher than with VHF systems and the quality of speech is generally poor. Unless equipped with expensive optional equipment, the conversations are in the half-duplex mode. Only one transceiver at the base station is shared by many rural subscribers (shared mode of operation) with the result that the traffic efficiency is low and the number of calls per subscriber extremely limited. While the investment cost of an HF system is comparable to that of a Single Channel VHF system operating in the shared mode, the operating costs are significantly higher because these stations have to be manned to effect frequent frequency changes. Thus, the use of HF systems is advantageous only when a minimum and low-quality communication is to be provided economically to communities which cannot for any reason be served by VHF systems, e.g., in remote localities or in difficult terrain. These systems have an application where the alternative to these systems for economic or technical reasons is no communication at all.
Multiple Access Radiotelephone System.

Base Station

Antenna Combiner

Radio 1

Radio 2

Radio 3

Radio 4

Radio 5

Radio 6

Radio 7

Radio 8

Base Radio Equipment

Terminal Control Equipment

Automatic Exchange with B-C Loop Supervision