TELEPHONY AND TELEGRAPHY*

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(1) INTRODUCTION

During the period under review the paramount importance of military requirements has influenced nearly all new construction and the development of telephone and telegraph services for business and social uses has been comparatively neglected. In both Great Britain and the U.S.A., however, the existence of a well-developed home-communication system, backed by an industry with considerable manufacturing resources and a substantial number of trained men, was a considerable asset to the prosecution of the war. The assistance rendered extended to the design and production of communication equipment specifically for service in the field and for other projects to which communication techniques were particularly adaptable. Some account of the war-time work of the British Post Office has already been given.‡

In previous reviews§ it has been customary to include a table showing the mileage of telephone and telegraph wire in the principal countries of the world and the extent of their telephone development as measured by the number of stations. Data are not available to-day regarding the mileage of circuits still working and the number of telephone stations still effective in many European countries. At the end of March, 1946, there were in the United Kingdom 3 610 automatic telephone exchanges, serving 2 580 028 stations, and 2 379 manual exchanges serving 1 309 211 stations. There were in addition many applications for telephone service which had not then been provided owing to shortage of plant. Very considerable expansion of the British trunk telephone network has taken place during the war period to meet the requirements of the Supply and Fighting Services for private telephone and telegraph circuits. Until 1945 very little of this expansion was available to extend the public service, but, even so, the number of public circuits over 25 miles in length had risen to 20% above the pre-war figure by August, 1944. At no time did it fall lower than about 8½% below the figure for August, 1939. The latest figures available show an increase of 80% above pre-war. The telephone networks remaining in most European countries are inadequate for the future needs of the communities which they serve, and the extensive reconstruction and development necessary present a unique opportunity for the planning of a comprehensive long-distance telephone network for Europe which would provide a quicker and cheaper service for the subscriber. This would utilize multi-channel carrier telephone systems and involve the remote control of automatic switches by means of voice-frequency currents. In Great Britain, such multi-channel systems, using either pair or coaxial cables, have become the recognized means of providing all circuits over about 50 miles in length, and the automatic switching of long-distance circuits under the control of an operator's dial has been developed to a considerable extent.

The telephone instruments in use to-day differ very little from those which were in production before 1939, but the requirements of armoured fighting vehicles and aircraft have caused much attention to be paid to the development of instruments giving the maximum intelligibility under conditions of loud noise. These instruments may not be suitable for use in ordinary telephone systems, but the lessons learned should be of value.

(2) THE IMPORTANCE OF MATERIALS

A most important factor affecting progress during the past six years has been the shortage of certain materials. For example, the multi-channel carrier telephone systems built in Great Britain and America have made extensive use of quartz resonators with a very low decrement in the electric filters for the separation of speech channels. Quartz units have also become almost indispensable for the accurate frequency-control of carrier-frequency generators in both line telephony and radio. The world supply of suitable raw quartz is, however, strictly limited, and, despite intensive search among a large number of chemical compounds exhibiting the piezo-electric properties necessary for this kind of electro-mechanical resonator, no suitable alternative has yet been found. Germany was isolated from the principal source of suitable quartz between 1939 and 1945; German carrier telephone equipment was therefore developed using coil-condenser filters to the greatest possible extent. On the other hand, iron dust made by the carbonyl process is the most suitable magnetic material available for the cores of inductors included in high-frequency circuits. Prior to 1939 it was manufactured exclusively in Germany, and some difficulty was experienced in Great Britain until a plant for the large-scale manufacture of iron dust by the carbonyl process had been constructed in 1942. The almost entire cessation of supplies of natural silk as a result of the spread of the war to the Far East in 1941 caused considerable attention to be given to the development of alternative materials for covering instrument and similar wires. Wrappings of cellulose acetate and regenerated cellulose made by various processes came into general use. Some of these were reported to be as good as natural silk in respect of abrasion resistance, space factor and suitability for impregnation, and were more liable to accelerate the corrosion of fine wires. Development of wires insulated by extruded coatings of various synthetic plastics was also accelerated, and polyvinyl chloride has been extensively used as a cable-covering owing to lack of rubber. The war demands for aluminium have necessitated the redesign of some telephone apparatus and the replacement of aluminium parts by zinc-base die-castings or synthetic-resin mouldings.

Another outstanding feature of war-time experience was the serious loss of equipment resulting from storage and use under severe tropical conditions. The improvements in moisture-proofing and packing, and the use of materials capable of withstanding extreme conditions of temperature and humidity, will be a benefit to future telephone and telegraph systems in tropical countries. Some of the techniques learned may also be advantageously applied where somewhat similar conditions exist locally, e.g. in mines.

Quite apart, however, from the changes brought about by shortage of the materials which were used in 1939, development of all telecommunication apparatus and systems is becoming increasingly guided by the advent of new materials. The improvements in transmission over long cables which followed the

* A review of progress.
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discovery of the nickel-iron series of alloys having very high initial permeability, and their introduction for the magnetic loading of cables, is past history. More recently the high magnetic energy of various alloys of iron with aluminium, nickel, cobalt, titanium, tungsten, copper and molybdenum has made possible the use of very small permanent magnets in telephone instruments. Use of the newer iron-oxide magnets may lead to more radical changes of design in the future.

Polythene was already developed in Great Britain, but was only just becoming available in quantity when the last progress review was written. Its great suitability as a low-loss dielectric (tan δ ~ 0.0003) for radio-frequency cables is well known, and its use has greatly facilitated the wiring of radar equipment. In addition it has completely replaced paragutta as an insulant for new submarine telephone cables. With a cable of the same dimensions the attenuation is about 10%, less with polythene than with paragutta, and this has enabled a useful number of additional carrier telephone circuits to be worked or planned over certain new cables between England and the Continent. During the last four years extensive study has been made in a number of laboratories of the preparation of ceramic materials with extremely high permittivities. Peak permittivities of over 10,000 have been reached using materials compounded of various titanates. The permittivity varies seriously with temperature, and the full applications of these materials have not yet been worked out, although they are likely to be extensive.

Symmetrical and asymmetrical non-linear resistors are being increasingly used as the basis of design for modulating and demodulating circuits and for detection of high-frequency currents. Selenium rectifiers, although well known prior to 1939, have in particular been considerably improved. A new range of complex metallic-oxide compounds having a high negative resistance/temperature coefficient has also been developed. Devices making use of this material, usually in the form of small bead-like elements, to give variable impedance are termed thermistors. They have already found application in oscillator circuits and for the equalization of the characteristics of transmission lines, and they appear likely to have various other uses.

Because of the growing importance of new materials to the development of telecommunication, manufacturing and operating organizations are devoting an increasing proportion of their research and development effort to work on materials.

(3) TELEPHONY

(3.1) Subscribers' Apparatus and Local Circuits

(3.1.1) Microphones and Telephone Receivers.

Research which was in progress, or planned, in various laboratories in 1939 had for its objective reduction of the distortion inherent in the carbon-granule microphone. Work of this kind had generally to be suspended on account of the research workers being otherwise engaged, and designs generally remain as they were in 1939. The British Post Office, in co-operation with telephone manufacturers, has, however, had under review for a considerable period the question of development of a two-electrode carbon-granule microphone having a better electrical performance than the present standard inset types. Although instruments showing this better performance have been produced experimentally, none has been yet put into commercial production or subjected to the test of extensive field use.

The position in 1939 with regard to British telephone receivers was that both those for use in the hand micro-telephone and those forming part of the operator's headset had been redesigned using a common magnetic system and giving a more uniform response over the speech-frequency range. Receivers of this type have a direct-action diaphragm, i.e. one which both acts as a sound radiator and forms part of the magnetic circuit. The use of modern magnetic materials makes it possible to obtain a volume of sound considerably in excess of the maximum tolerable, and part of this excess may be sacrificed in the elimination of the mechanical and acoustical resonances. Receivers of this type with equalized response have been manufactured in quantity for the Navy, Army and Air Force during the war period. Another type of telephone receiver in which the sound-radiating diaphragm does not form part of the magnetic circuit has been developed, and approximately 22 millions were manufactured for the Fighting Services. A balanced-armature magnetic drive is used and has the advantage that the magnetic and acoustic elements may be designed independently. Receivers of this second type normally have a considerable sound output, and their use frequently obviated the necessity for amplifiers. Equalization by the damping of resonances also becomes practicable.

The means by which the recent war was fought involved the use of inter-communication systems in very many aircraft and armoured fighting vehicles where the noise was so loud that ordinary conversation was impossible. Radiocommunication to and from these aircraft and vehicles had also to be maintained. This has caused much attention to be paid to the development of telephone circuits to give the maximum intelligibility under such conditions of noise. The problem is not one that usually arises in civil telephony, although it may be encountered to a lesser extent in such locations as factories and noisy offices. Satisfactory use of carbon-granule microphones in noisy locations depends on the extent to which the noise can be excluded from the microphone and to which this can be rendered insensitive to the components of frequency which are predominant in the noise. A number of American designs have been evolved with these objectives in view. In general, however, the normal inset types of carbon-granule microphone cannot be successful in locations where the noise level exceeds 90 phons, which is roughly equivalent to the noise in a railway carriage when the train is passing through a tunnel. A miniature electromagnetic moving-iron unit, which was first made in the U.S.A., was redesigned and adapted to production in this country for use as either a microphone or receiver unit. It has been used in large numbers by the R.A.F. Electromagnetic moving-coil microphones and receivers have, however, been used in very large numbers, and they have in general been found to be the most successful types where the noise was loudest. Comparatively cheap units with good characteristics have been manufactured. In general the conclusions of all workers in this field have been that the overall response of any speech-transmission system for use in loud noise, including the microphone and telephone receiver, should have no sudden change in efficiency due to that part of the speech-frequency range transmitted. Moving-coil units most nearly meet these requirements. They are not, however, generally suitable for civil use owing to their being more bulky, more expensive and having a smaller electro-acoustic efficiency than the instruments at present in use.

(3.1.2) Private Branch Exchanges.

A few improvements have been made in private branch exchange equipment available to British subscribers. A new multiple 24-volt private manual branch exchange switchboard (P.M.B.X.) with lamp signalling was introduced in 1941. It has a maximum capacity of 800 internal extensions and 160 exchange lines or external private circuits. A divided feed is provided on inter-connection calls, and metallic connection with through-clearing, operator-recall, and follow-on call-trap facilities on exchange calls. Two types of relay set are available for the
external private circuits: one is equipped with a Stone transmis-

tion bridge suitable for d.c. signalling, and the other with a

transformer bridge suitable for generator signalling.

An ingenious type of frequency converter first used in America

is now also being used to a considerable extent in Great Britain
to supply ringing current at 16f/s to large P.M.B.X.'s and

small manual exchanges. The supply is derived from the 50-c/s

mains by way of a parallel-resonant tuned circuit in series with

an inductor which saturates at intervals of 0-03 sec when the

50-c/s and 16f/s oscillations are momentarily in phase, and, in

so doing, permits a pulse of current to pass to sustain the low-

frequency oscillation. A 100-c/s supply was required during the

war for the remote operation of tuned mercury switches

controlling air-raid warning sirens, and is now used for controlling

fire-call sirens. This supply is again derived from the 50-c/s

mains, copper-oxide rectifiers being used to produce the second

harmonic of the lower-frequency current.

(3.1.3) Local-Line Development.

Between 1939 and 1945 the provision of new cables for con-

necting British telephone subscribers to their local exchanges

was only sufficient to meet the requirements of the Fighting and

Supply Services with other essential war-time facilities. Only a

proportion of the cables installed is likely to fit in with normal

peace-time needs during the next few years. In towns which

have suffered severely from air-raid damage, reconstruction may

cause future telephone requirements to differ considerably from

those existing six or seven years ago, and provision must be made

for the development of industrial and residential areas where

there are at present only a few subscribers. The building of new

exchanges and the installation of many new local cable networks

will be necessary. As long-term forecasts are not usually realized in practice, even under normal conditions, it is partic-

ularly essential that new construction should give the maximum

flexibility for rearrangements. Some review of the various means

of providing local-line plant should therefore be of interest.

In America the problem of rapid expansion of the telephone

service following correspondingly rapid growth of new built-up

areas has been much more serious than in Europe. Throughout

North and South America the main feature of the system in use

is that connections to the wires in the main cable are brought out in

parallel by stub cables at a number of jointing points. The

system enables uncertainties of development to be met, obviates

the frequent opening of joints, and facilitates the connection of

new services or the transfer of a block of territory from one

exchange area to another. On the other hand, cable breakdowns

may cause more disturbance. In Australia a certain amount of

flexibility in the cable distribution is obtained by means of con-

crete distribution pillars. Each of these accommodates approxi-

mately 80 subscribers' lines, and they are installed on the exchange

system at selected points. A somewhat similar system, but using

cabinets housing cross-connecting terminals sufficient to cater for

up to 300 subscribers, has been used extensively in Sweden, Den-

mark, Switzerland and Poland.

It is probable that all future development in Great Britain will

make use of the greater flexibility provided by the American

cable layout, together with new cabinets and pillars which have

been designed in this country and will provide the cross-connect-

ing facilities. The successful use of silica gel as a desiccant

within sealed apparatus cases suggests that low insulation re-

sistance resulting from condensation is no longer an objection to
cross-connecting devices.

Cable containing conductors weighing 61 lb/mile is the smallest

conductor size at present used in this country. The possibility of

using 4 lb/mile conductors for local-line development has been

under consideration for many years, but these conductors

are rather fragile, and their use might lead to trouble in the

rearrangement of joints. A multiple teeing system with cross-

connecting frames would render such rearrangements unneces-

sary. With the modern type of telephone, and without departing from the present quality of transmission, nearly 2 miles of this

small-conductor cable could be tolerated between the exchange and the subscriber. This conclusion is based on the use of what

is becoming known as the effective transmission method of rating a telephone circuit. "Effective transmission" is a means of

measuring the capability of a circuit to transmit intelligence, and as such must be determined finally by a subjective test. The

counting of repetitions during a conversation has been interna-
tionally agreed as the best criterion available at the present time for assessing effective transmission, but such tests are too

cumbrous and lengthy for normal use, and other methods of

obtaining the information have been worked out. Effective

transmission allows full advantage to be taken of the improved

transmission qualities of modern circuits.

(3.2) Telephone Switching Systems

The precautionary measures undertaken by the Post Office
during the war period included the building in London of a heavily

protected trunk exchange. This combined the functions of providing relief for the existing exchanges and of maintaining

essential communications should the existing exchanges have

been destroyed. A new feature was introduced in the arrange-

ments for quoting to the operators the expected delays for com-

pleting calls on heavily loaded routes. The announcements are

made by machines in which are photo-electric cells for repro-
ducing various standard-delay announcements from sound tracks
on glass discs. New toll exchanges were also opened to meet

the increased load and as a safeguard against the loss of existing

exchanges.

New circuits required in remote places under war conditions

could often be quickly built up from those already existing, but

were unable to transmit 17-c/s ringing current; the standard

voice-frequency ringing and signalling equipment did not exist.

For such cases a voice-operated relay was developed which

enabled simple calling signals to be passed from one end of the

circuit to the other, merely by speaking on the circuit. The unit

obtained all its necessary power supplies from the lighting mains.

Telephone switching and signalling apparatus has been adap-

ted to various war-time projects, of which the remote control

of air-raid warning sirens and the provision of automatic

computers and message recorders for reporting the position of

aircraft located by coastal radar stations are examples.

(3.2.1) Exchange Apparatus and Equipment.

The mechanical regenerator mentioned in the last review has

been successfully introduced into the Post Office system in fair

numbers as a means of avoiding the cumulative distortion of
dialling impulses.

Another British innovation has been the use of mobile-unit

automatic exchanges to provide service in small communities,

for example during the re-equipping of an exchange or under

emergency conditions such as damage to an exchange by fire.

The intention of the British Post Office to provide new types of

power plant was announced several years before the period

covered by this review, but these were not installed in any great

numbers until 1938. There are four types of new plant, the

choice of type in any given case being governed by the anticipated
daily ampere-hour consumption when the exchange is fully

devolved. The chief features are the reduction in the sizes of

the batteries provided, with floating of the batteries across

rotary machines in the largest installations and rectifiers in

the smaller ones, together with close regulation of the busbar

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voltage. For the last feature, alkaline counter-e.m.f. cells of the non-charging variety have been developed.

(3.2.2) Multi-Metering and Automatic Ticketing.

The installation in this country of equipment permitting subscriber-dialling with multi-metering of the appropriate charges up to 15 miles' radial distance, as mentioned in the previous review, has been greatly held up by the war, but some progress has been made in London with the object of relieving the shortage of operating staff. This work was possible because, in addition to multi-metering equipment which had already been provided at some exchanges but not brought into use, service to and from some other exchanges could be made available by a relatively small amount of modernization to existing equipment. The installation of multi-metering equipment is one of the urgent post-war problems in this country, where considerable simplification of the original system is now contemplated.18 Extensive use of multi-metering is also planned in other countries.

An alternative to multi-metering is the automatic ticketing of telephone calls. The first installation at Bruges has been extended to other parts of Belgium.19 Automatic ticketing has also been installed in the U.S.A. between Culver City and Los Angeles.20 Automatic ticketing is particularly useful where flat-rate local service has resulted in subscribers not being provided with individual meters.

(3.2.3) Trunk and Toll Switching Equipment.

In the last review a fairly full description was given of the system of signalling and dialling by means of voice-frequency currents at 600 and 750 c/s, which it was proposed to introduce into the trunk system of Great Britain. This system has since been described in greater detail.21 The first circuits mechanized in this way were brought into service between London and Bristol in June, 1939. Equipment was rapidly installed at other centres, and, in April, 1946, 2115 circuits between the principal zone centres in Great Britain were being operated in this way. The system enables the operator at the outgoing trunk centre to complete the setting up of a connection to a wanted subscriber within the area of the distant centre without the assistance of any other operator. The present installation in Great Britain represents a greater amount of mechanization of long-distance switching than has taken place elsewhere. Although the system could be improved by the adoption of techniques developed since it was designed, it has satisfactorily provided the facilities which were originally intended.

Mechanized switching of long-distance connections, using British designs and equipment, has also been introduced to a considerable extent in Australia.22 With this system, operators at provincial centres in the State of Victoria can obtain connection to subscribers in the Melbourne area by automatic switching. Operators in Melbourne trunk exchange can similarly obtain subscribers on provincial automatic, and operators on provincial manual, exchanges. Provincial-to-provincial exchange calls which need to circulate through Melbourne are there handled semi-automatically, and this also applies to inter-State calls, which are always handled on a delay basis. Incoming calls to the manual positions, which are all of the cordless desk type to be referred to later, are queued and are thus answered strictly in order of their arrival, an illuminated column indicating by its height the number of calls awaiting attention. Outgoing calls are set up by key-sending into a local sender which controls the selectors and, if all direct circuits are found to be engaged, automatically attempts to redirect the call over a different route. If all alternative routes are found to be engaged the sender tries the main route again, and if no free circuit is available the call is stored. Supervisory signals are given to the operator to inform her of the state of the connection, including when a circuit in the wanted group becomes free; it can then be easily picked up by operation of a key. The automatic aids to operating provided in this system enable high loads to be carried both by the operator and the trunk circuits, and the centralized and highly-developed supervisory arrangements enable the state of the traffic to be constantly under supervision. Depending upon the type of line, the line signalling is by either direct or voice-frequency current using the internationally standardized frequencies of 600 and 750 c/s. The automatic-switching equipment is the type which employs single-motion selectors of large bank capacity with wipers driven at high speed by a motor.

In the U.S.A., equipment which has been in operation in Philadelphia since 1943,23 provides semi-automatic trunk service from cordless desk-type boards. The operators set up numbers by key-pulsing into local senders as in the Australian system. Similar pulsing also takes place between senders in different exchanges, each digit being represented by two out of six possible frequencies and the digits being transmitted at the rate of ten per second. Automatic alternative routing is a feature of the system. The installation at Philadelphia is the first of a number of automatic trunk exchanges which are intended eventually to enable the setting up of a connection between any two subscribers in the U.S.A. to require not more than one operator. Similar systems for Germany24-25 were planned before the war and are contemplated in most other countries.

It is in the field of long-distance switching that the greatest developments are likely to take place in the immediate future. All the major countries are considering the mechanization of their trunk systems; the first step promises to be semi-automatic working with one operator able to connect to any subscriber in her own country and to some subscribers in neighbouring countries. At the same time the range of self-dialling by subscribers will be extended as improved signalling systems come into operation, and as automatic means for determining the charge for the calls, either by multi-metering or automatic ticketing, become available. Though the present state of development of long-distance switching systems is still somewhat fluid, it is possible to distinguish the salient features of the new systems.

Since operators' switchboards will not need multiples, selection being done by switches, they can be made more like desks, with advantages to the layout and the lighting of switch rooms. Also, they will be without cords, all controls being by lever or press-button keys. There is also a strong tendency towards key-sending being substituted for dialling by operators. The switching equipment, being automatically operated, offers better scope for more complex operations than manual switching. Four-wire switching of four-wire circuits, and the control of overall loss of trunk circuits by automatic switching-in of repeaters and attenuation pads as appropriate, are prominent in the new systems. Four-wire switching, which is a feature of both the Australian and the American installations already referred to, also allows the precision balancing of two-wire circuits when they are switched to four-wire circuits. With better balancing, the long-distance circuits can be worked with less loss in the speech-transmission path.

(3.3) Long-Line Transmission

Prior to the war a small network of private telephone lines was available to the Services. In 1939 a programme of expansion was undertaken to meet the ever-growing needs of war in respect of British industry, and the Supply and Fighting Services. Until the middle of 1944 the increase in Service circuits over 25 miles in length was almost uniform at about 1 900 circuits per annum,26 and by August, 1944, the peak value of 9 300 was reached. This
is nearly one and a half times the total pre-war network of 6,800 circuits. All this was accomplished without serious re-
duption in the public service, which had actually expanded sub-
stantially at the end of the period. The expansion was obtained
mostly by circuits on 12-channel carrier and coaxial cables, but,
in addition, more than 400 main audio cables of various lengths
and sizes were laid during the war years.
During this period the development of 12-circuit carrier tele-
phone systems on multi-pair cables based on the Bristol–Plymouth
system of 1936, and that of wide-band carrier systems on coaxial
cables based on the London–Birmingham system, have pro-
ceeded side by side. Because of the somewhat simpler nature of
the equipment associated with the 12-circuit systems, these were
the first to be generally adopted, and an extensive cable network
has been laid and equipped in this way. As development of
wide-band systems proceeded it became evident that these would
prove the more economical means of providing large numbers
of circuits even over moderate distances. In order to maintain
flexibility of the carrier system and at the same time to avoid
undue expenditure on terminal equipment, it is now the practice
to interconnect 12-circuit and coaxial systems on distribution
frames in the frequency range 60–108 kc/s, i.e. without translation
to audio frequencies.

(3.3.1) 12-Circuit Carrier Systems on Cables.
A total of 6,300 miles of 24-pair cable is installed, each
pair providing twelve unidirectional speech channels in the fre-
quency range 12–60 kc/s. Within limits, an 18-channel carrier-
telegraph system can be worked over any telephone channel.
Soon after this network was commenced it was found practicable
to operate 24 telephone channels over each pair, and a large part
of the network is designed with a view to increased utilization
in this way. Thus, the maximum repeater station spacing is now
15 miles against 22 miles in the earlier installations, permitting
transmission of a frequency band of 12–108 kc/s without excessive
attenuation of channels. Elsewhere a practice is used, where
channel equipment is not uniform, of using a smaller supergroup
in such pairs so that the frequency range 60–2,852 kc/s is
reduced considerably. In the U.S.A. there seems to be no suggestion
of transmitting more than 12 channels over each cable pair; in
Holland a total of 48 channels per pair is planned.
The channel equipment used on 12-circuit systems has been
redesigned and is now uniform with that used on wide-band
systems. In accordance with international agreement the lower
sidebands of the modulated audio-frequency speech channels are
first assembled in the frequency range 60–108 kc/s. This is
known as the primary group. To translate this primary group
into the agreed international 12-channel frequency band of
12–60 kc/s with upper sidebands, a group modulation with a
carrier of 120 kc/s is used. When a second 12-channel group is
transmitted over the same pair, the primary group is used
directly.
During the war years, the carrier frequencies employed on 12-
circuit systems in Great Britain have been stabilized by means of
60-kc/s pilot tones transmitted over each route, and the systems
are thus virtually synchronized. While this has been essential
with the type of frequency generator so far used, the system has
become very involved and may be abandoned in favour of
highly stable local frequency-generators.
In Great Britain automatic gain-regulation and equalization of
the systems has not so far been employed, but in the longer
systems common in the U.S.A. and elsewhere this type of con-
trol has been found essential.

(3.3.2) Wide-Band Carrier Systems on Cable,
Terminal and repeater equipments for wide-band systems are
now reasonably well developed, and an extensive coaxial-cable
network is being constructed. Up to the present 2,400 miles
of coaxial cable have been laid; this involves 4,130 miles of coaxial
pairs (or tubes) in one-, two- and four-pair cables. The frequency
range transmitted over these cables has not been standardized,
but a range of 60–2,852 kcfs is common on a coaxial pair of
0.37 in diameter, with a repeater spacing of six miles. This
system will provide 660 circuits on two coaxial pairs.
The frequency allocation of the channels was provisionally
agreed internationally in 1938, all carrier frequencies being
multiples of 4 kcfs. In Great Britain, the agreed arrangement is
met by the use of the same primary group as for 12-circuit
systems and the assembly of a primary supergroup in the range
312–552 kcfs. This primary supergroup is modulated to form
further supergroups in the frequency ranges 60–300 kcfs, 564–
804 kcfs and higher supergroups separated by 8-kcfs gaps.
The use of carrier systems, in particular wide-band systems,
leads to simplification of cables at the expense of great elaboration
of terminal equipment. This has two important repercussions.
First, the majority of circuit faults are equipment faults and a
high standard of construction and maintenance is essential.
Secondly, since the greater part of the circuit cost resides in the
maintenance of the terminal equipment, this cost becomes more
nearly independent of the route mileage as the number of channels
per cable pair is increased.

(3.3.3) 12-Circuit Carrier Systems on Open Wires.
The British trunk network is almost entirely underground, and
long-distance open-wire circuits have no place in it. The applica-
tion of modern carrier systems to such lines is therefore of little
interest in this country, but this is far from true in countries like
the U.S.A. and the Dominions, where distances and telephone
densities do not always warrant expensive underground plant.
In such countries, the efficient utilization of open-wire routes is
of great importance.
Until 1938, open-wire carrier systems usually operated at fre-
quencies below about 30 kcfs, providing, typically, one audio-
and three carrier-telephone circuits per pair. In 1937 the fourth
transcontinental line was built in the U.S.A. from Oklahoma
City to Los Angeles, and the construction was such that fre-
cuencies up to 140 kcfs could be satisfactorily transmitted.
A high standard of line construction and maintenance was called
for, but it was possible to operate a 12-circuit carrier system on
each pair at frequencies between 30 and 140 kcfs, the channels
being spaced at the usual 4 kcfs. On such a route, variations of
the line losses under changing weather conditions are enor-
mous, but these have been successfully counteracted by auto-
matic regulation of repeater gains at several frequencies
within the transmitted frequency bands. The development of
the thermally dependent resistor, or thermistor, has recently con-
tributed much to the successful design of such regulators.
The use of 12-circuit carrier systems on open wires has now
been extended to many countries. A competitive German
system provides 15 circuits but at a channel spacing of 3 kcfs
and of correspondingly lower quality. The success of the
Germans in designing this and other carrier systems without the
use of materials such as quartz, which were freely available to
other nations, is notable.

(3.3.4) Negative-Feedback Amplifiers.
The great developments in carrier telephony in the last decade
have largely been made possible by the application of negative
feedback to linearize the characteristics of amplifiers handling a
number of simultaneous conversations. It has now become
usual to apply this measure of stabilization to all amplifiers
used in line communication, and the characteristics of both
audio and music amplifiers have been considerably improved.
This improvement has been accompanied by further reductions
in bulk and cost.
Whereas it was usual, in 1939, to employ in audio-frequency
amplifiers specially constructed valves to meet close performance tolerances, it is now easily possible to employ valves mass-produced for the radio industry at a fraction of the cost. The wider tolerances applicable to this type of valve are effectively reduced by the negative feedback.

(3.3.5) Submarine Cables.
In 1940 all submarine telephone cables linking this country with the Continent were severed, only those to Northern Ireland, Eire, the Isle of Man and some of the Scottish Isles remaining in operation. During the war additional cables were laid in home waters; these were all of the coaxial type with paragutta dielectric to 0-62 in diameter. Circuits were provided over these cables by means of standard carrier-telephone equipment, together with high-power transmitting amplifiers and directional filters to enable the same cable pair to be used for two directions of transmission in different frequency ranges. Special attention was given to methods of providing the maximum number of circuits with a view to the most efficient utilization of the cables. The technique consisted essentially of:

(a) Eliminating all forms of interference in cables and equipment to a point where the only limitation to the permissible receiving level is the irreducible noise due to thermal agitation in the conductors.

(b) Increasing the transmitted power to an economic maximum, consistent with a high degree of linearity in the transmitting amplifier.

(c) Design of repeaters suitable for use on the sea bed.

Special mention should be made of the cross-Channel cables provided and equipped for the Armies of Liberation in 1944. Prior to the invasion many routes were planned and provided for; events moved in such a way, however, that they were not all equipped. The earlier cables were insulated with paragutta, but as stocks became exhausted polythene was substituted; this reduced the attenuation coefficient and made it possible to work over rather greater lengths than were originally planned. The terminal equipment used on the cross-Channel cables was, as has already been stated, based on developments carried out earlier in the war. Three types of system were used, the first providing 4 circuits per cable on the longest routes, the second 12 circuits per cable on the medium routes, and the third 60 circuits per cable across the Straits of Dover. In all, ten new coaxial submarine cables were laid before the cessation of hostilities in Europe. With four pre-war cables restored to service, these provided a total of 185 circuits as compared with a capacity of 215 in 1939; the capacity has since been increased to 235 circuits and a total of 185 circuits as compared with a capacity of 215 in 1939; the capacity has since been increased to 235 circuits and a total of 185 circuits plus a 1 audio + 4 carrier-circuit system suitable for both open-wire lines and a specially loaded field-cable. While these systems are generally much more compact than their civil prototypes, the process of "miniaturization" applied to much radio and radar equipment was never seriously attempted with line equipment.

(3.4) Military Line-Communication
Prior to 1939, British military line-communication had not kept pace with advances in the technical development of the civil system. The early years of the war, however, saw the adaptation of civil designs, leading to a flood of first-class equipment in the later phases of the war. The basic systems adopted were 1 audio + 1 carrier and 1 audio + 3 carrier circuits for open-wire lines, each consisting of 1 audio + 4 carrier-circuit system suitable for both open-wire lines and a specially loaded field-cable. While these systems are generally much more compact than their civil prototypes, the process of "miniaturization" applied to much radio and radar equipment was never seriously attempted with line equipment.

(4) TELEGRAPHS
The main trunk telegraph network of Great Britain continues to be provided by 18-channel, and to a smaller extent 12-channel and 4-channel, voice-frequency telegraph systems operating over telephone circuits, and described in the review of 1939. The
war necessitated a great increase in the number of channels, to provide for the requirements of the Fighting Services. To meet these requirements a special private network known as the Defence Teleprinter Network (D.T.N.) was set up, and by 1944 this network comprised more than 7000 channels as compared with about 2000 channels for the inland public network.

Development of mobile multi-channel voice-frequency telegraph terminal equipment was made necessary. Some of the vehicles equipped for this purpose will be retained for peace-time use in meeting emergencies or in cases where services must be provided before permanent buildings are complete.

(4.1) Telegraph Switching Systems

A large proportion of the D.T.N. circuits was manually switched, and, in order to give the flexibility required on a service network, the switchboards designed for the purpose provided full ancillary working, i.e. there was a common calling and answering field, enabling any operator to deal with any call. Conversion of the public telegraph network in Great Britain to automatic switching has been postponed as a result of the war. As an interim measure to reduce retransmission of telegrams, a manual switching system is being introduced and installation is already well advanced. This system broadly follows telephone-switchboard practice, but each circuit in the calling field is multiplied over a number of operating positions. In this manual switching system, as well as in that provided for the D.T.N. circuits, communication between the operator and the subscriber is entirely by teleprinter.

A fully automatic switching system was introduced in the civil network of Germany before and during the war for Government Services and private subscribers. This network comprised six main and many subsidiary switching centres. It covered almost the whole of Germany and extended to parts of Denmark, Holland, Switzerland and Czechoslovakia.

(4.2) Telegraph Transmission

(4.2.1) Line Systems

Systems designed to provide one simplex or duplex voice-frequency telegraph circuit as well as speech over a telephone circuit of normal band-width have been used for British military communications and for some other special applications. A frequency band, usually between 1 500 and 2 000 c/s, is allocated to the telegraph circuit, and the speech and telegraph circuits are separated by band-pass and band-stop filters. Owing mainly to the consequent degradation of speech quality, the system has not been adopted for civil use.

In America frequency-modulated multi-channel voice-frequency telegraph systems have been developed, primarily for use on open-wire lines, and, it is claimed, give more stable operation and greater immunity from noise than the standard amplitude-modulated system. Two systems are used: a narrow-band system for teleprinter working, with 150-c/s channel spacing and 70-c/s frequency shift to indicate the change from mark to space signals; and a wide-band system for high-speed working, with 300-c/s channel spacing and 140-c/s frequency shift.

Progress has been made in the method of operation of d.c. submarine telegraph cables of a few hundred miles in length, by the use of amplifiers, with subsequent artificial restoration of the d.c. component, and by the application of telephone circuit technique in equalizing the attenuation and phase characteristics over the relevant frequency range. The system provides very stable operation, and maintenance is greatly simplified.

(4.2.2) Radio Systems

Teleprinter operation, both single- and multi-channel, over long-distance, short- and long-wave radio links has been developed since 1939, and has been rendered possible by the use of methods designed to reduce the effects of noise and fading. Multi-channel voice-frequency telegraph systems are satisfactorily operated by the adoption of two-tone working, in which two channels are allocated to each telegraph circuit, a tone being transmitted on one channel for a mark and on the other for a space. In addition, frequency- or space-diversity reception, or a combination of both, are often used when selective fading conditions are severe. On single-channel radio links, frequency shift, i.e. direct frequency modulation of the radio-frequency carrier, is used.

Special codes have been devised with the object of improving the detectability of errors, and are applied mainly to time-division multiplex systems. One of these, introduced in America, is a 7-unit code, each character containing three marks and four spaces. Any received character not consisting of this combination is apparent as an error.

(4.3) Telegraph Apparatus

(4.3.1) Machines

Hell-Schreiber apparatus, referred to in the 1939 review, continues to be used on radio links. Improvements in detail of teleprinters and in 5-unit and morse-telegraph machines have taken place, without, however, any change of basic principles. Teleprinting reperforators (in America called typing reperforators) have recently been introduced; these machines reperforate received teleprinter signals and print the corresponding alphabetical characters on the same slip, and simplify the handling of traffic when retransmission of messages is necessary. The use of teleprinter automatic transmitters has extended, and automatic message-numbering machines have been introduced which insert the appropriate serial number before each message is transmitted.

Developments have taken place in the design of telegraph relays, with the object of improving sensitivity and efficiency, and of reducing size. Improvements have also been made in apparatus for measuring telegraph distortion and for monitoring the grade of service on working telegraph channels.

(4.3.2) Picture Telegraphy

No great changes have occurred in the basic principles of picture-telegraph apparatus, but developments have taken place in the method of transmission over radio links, with the object of reducing the deleterious effects of noise and fading. A method widely used is known as sub-carrier frequency modulation. In this system an audio-frequency carrier is frequency-modulated in accordance with the shade of the element of the picture being scanned. The system commonly used at present employs a frequency change from 1 600 c/s for black to 2 000 c/s for white, but another uses 1 800 c/s for white and 3 000 c/s for black; there is at present no internationally agreed standard. The f.m. signals are transmitted over the radio path, usually by amplitude modulation of the radio-frequency carrier; they may also be transmitted over land lines provided these have a sufficiently high cut-off. Direct frequency-modulation of the r.f. carrier has also been used.

In America, a facsimile system has been developed for the automatic transmission of telegrams to a main telegraph office from an unattended sub-office. The subscriber writes the telegram on a form and inserts it in the machine, which then scans it in the manner normal for the transmission of pictures and transmits the signals to the main office. Here the telegram is reproduced directly on special paper which obviates photographic processing. The same type of equipment is used on train-order circuits.
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