THE TANGIER RADIO RELAY SYSTEM*

BY

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Summary—*Long-range radio communications in the short-wave band are adversely affected by magnetic disturbances, aurora, and solar activity. The effects are most severe near the polar regions. In order to circumvent this difficulty in circuits between New York and parts of Europe and Asia, a relay station has been set up at Tangier. This paper examines the reasons for choosing Tangier as the site, and describes the equipment necessary to meet the requirements of a modern communications system offering high-speed telegraph, telephone, and radiophoto services.*

INTRODUCTION

THE first commercial radiotelegraph circuits were operated in the long-wave band between 15 and 500 kilocycles. While these circuits could provide communications over virtually the entire world, they had several rather serious drawbacks. Foremost among these was the noise, or "static" as it was then called, which sometimes made long distance communications difficult, or even impossible. This noise was chiefly due to electrical storms, and so was particularly annoying in the tropics and other areas where such storms commonly occur.

The most obvious method of increasing the signal-to-noise ratio was by increasing the power output of the transmitters. In some cases, the use of directional receiving and/or transmitting antennas would provide additional improvement. Both of these approaches were followed, but rather severe practical limitations restricted their usefulness.

Communications in the long-wave band requires large amounts of power because of the low efficiency of antennas used for these wave lengths. The radio-frequency generator must supply some 10 to 20 times the power actually radiated by the antenna. As a result, 200-kilowatt and even 500-kilowatt alternators were common in the early days of radiotelegraph. At these levels, the power increase which would be needed to provide a significant improvement in signal-to-noise ratio at a distant point, would be entirely out of the question from an economic standpoint.

Similarly, the improvement which was theoretically possible with

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directive antennas was difficult to achieve in practice. The beam width of a directive antenna is roughly proportional to the number of wave lengths contained in the radiating elements. Because of the long wave lengths involved, highly directive antennas were not feasible. For example, at 20 kilocycles the physical length of a wave length is 9.3 miles. The construction of gigantic structures required to support a reasonably efficient transmitting antenna of that type was impractical.

Another growing pain experienced by the wireless communication industry was the lack of space in the radio spectrum. Because of the large demand for frequencies in the long-wave region, there was little chance for expansion of commercial communication services.

As a result of these difficulties, communications engineers turned their attention toward the short-wave bands (4 to 22 megacycles) which were known to have certain advantages over the longer waves, and where much of the spectrum was unused. During the early 1920's, considerable effort was expended in the development of short-wave radio techniques, so that in 1925 it was possible to establish a direct short-wave radiotelegraph circuit between New York and Buenos Aires. This proved to be superior to the existing long-wave circuits in several respects. Less power was required, smaller antennas could be used, and the disruption of service by noise was much less frequent.

The success of this initial installation brought about the replacement with short-wave equipment of most of the long-wave gear used for circuits to South America. In addition, short-wave circuits were established for traffic with several European cities. On these European circuits, however, certain effects were discovered which were not present on the South American circuits. Large, rapid changes in signal intensities were observed, and occasionally there would be complete absence of signals for extended periods of time. There were also wide variations in signal intensities received from day to day and from hour to hour. These effects were in addition to the normal fading found on most long-range, short-wave circuits. The disturbances appeared to be most severe in circuits between New York and the northern countries of Europe. It was also found that circuits to the Orient in which the great-circle paths passed over the north polar region were completely obliterated most of the time.

Within a few years, techniques had been developed which permitted reliable short-wave communications on the European circuits during all but the most severe of the disturbances. Perhaps the most important single development in this respect was space diversity reception,[1] which

[1] H. H. Beverage and H. O. Peterson, "Diversity Receiving System of RCA Communications, Inc. for Radiotelegraphy," *Proc. I.R.E.*, Vol. 19, pp. 531-561, April, 1931.

consists of a system of two or more directional receiving antennas spaced a sufficient distance apart so that the signal intensity on one antenna usually increases when there is a decrease in the signal received on another. The signals from these antennas are fed into a diversity receiver which automatically selects the one of greatest intensity, thus reducing the effects of signal fading. By using long-wave circuits during the disturbed periods, continuously reliable communications were possible.

PROPAGATION STUDIES

Extensive studies were made of the vagaries of short-wave propagation. These seemed to indicate a correlation between field intensities and conditions of terrestrial magnetism.[2] Short-wave propagation over long distances depends on reflections of the transmitted wave by the E and F layers of ionization which form the ionosphere. When these layers are disturbed by ionospheric "storms," propagation is erratic in the disturbed areas. This effect had not been evident in the long-wave circuits.

Further studies showed that the periods of greatest ionospheric storms were also periods of greatest sunspot activity, and that the intensity of the storms was greatest near the north magnetic pole, in the Northern Hemisphere. Since means of predicting sunspot activity were known, this offered an approach to the prediction of short-wave propagation conditions. As a result of these discoveries, it was possible to establish zones which were designated as "effective," "disturbed," and "dead" with respect to a fixed communication center. Figure 1 is a chart of these zones about New York for the year 1942. There is no indication of the degree of disturbance, but actually there is an inverse relationship between the severity of the disturbance and the distance to the disturbed zone for all circuits outside of the zone. The intensity also varies with solar activity, but the location of the maximum disturbance in the zone does not change appreciably. The zones illustrated conform with actual propagation conditions experienced during 1942.

It can be seen from Figure 1 that the cities of northern Europe and India lie in the disturbed zone. One method of obtaining reliable short-wave communications between these cities and New York is to employ a relay station at a location which does not lie near the disturbed zones of either New York or the cities of northern Europe.

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[2] H. E. Hallborg, "Terrestrial Magnetism and Its Relations to World-Wide Short-Wave Communication," *Proc. I.R.E.*, Vol. 24, pp. 455-471, March, 1936.

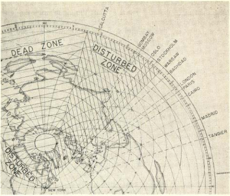

Fig. 1—Average disturbed and dead zones about New York for short-wave signals during 1942.

The seaport of Tangier is so situated. Figure 2 is a chart showing propagation zones with respect to Tangier. It might be supposed that

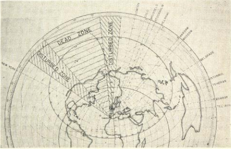

Fig. 2—Average disturbed and dead zones about Tangier for short-wave signals during 1942.

a location farther from the magnetic pole would be more desirable, but as the distance from the equator decreases, the noise increases. While the noise is much less troublesome on the short-wave than on long-wave circuits, it can, nevertheless, become a limiting factor in the tropics. On a noise scale which ranges from 1 to 5, Tangier has an annual average of 2½.[3] Approximately the same figure applies to Riverhead, Long Island, New York, where the RCA Communications main receiving station is located. Tangier, then, represents a good compromise between the opposing factors.

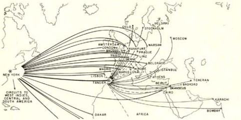

Fig. 3—Circuits between New York and Europe and the Near and Middle East.

The utility of a relay station in northern Africa was demonstrated by the U. S. Army station which was put into operation in Algiers in 1944. This station enabled considerably more reliable Morse and teletype service between the United States and our armed forces in Europe than had been possible on direct circuits.

The Tangier Relay Station

In early 1946, RCA Communications Inc. installed a relay station on the northwest tip of Africa in the Tangier International Zone. The site of the station is approximately 16 miles south of the city of Tangier, Morocco. Figure 3 shows the traffic circuits that pass through the station. The principal purpose of the installation was to serve as a link in the New York–Moscow and New York–Bombay circuits, enabling continuous reliable short-wave communications between these

[3] "Ionospheric Radio Propagation," *National Bureau of Standards Circular #462*, pp. 151-162, U. S. Government Printing Office, Washington, D. C.

cities. Soon after inauguration of this service, its usefulness was established for relaying traffic between New York and other cities in Northern Europe during periods when the space paths of the direct circuits were adversely affected by severe ionospheric storms and auroral phenomena. The value of the station is indicated by the fact that its facilities have increased approximately sixfold since 1946.

A plan of the station is shown in Figure 4. The administrative

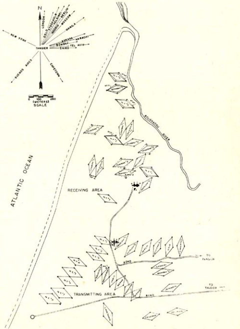

Fig. 4—Plan of the Tangier Relay Station.

offices are located in the receiving area in the northern part of the property, and the diesel-electric power station and the fresh water supply and pumping station are in the transmitter area in the southern part. The main diesel-electric unit is a low-speed machine capable of delivering approximately 400 kilowatts of 230-volt, 3-phase, 60-cycle power. This is shown in Figure 5. In addition, there are 8 standby units, each rated at 50 kilowatts. There are provisions for synchronizing the standby units so that they may be added to the main line

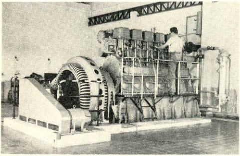

Fig. 5—400-kilowatt diesel-driven generator.

without interrupting the power supply. Step-up transformers provide 2300-volt power for transmission to the central radio office and receiving station. This is carried by two underground cables, either of which is capable of supplying the entire load. The voltage is stepped-down to 230 volts for use at these locations.

Fresh water is obtained from a deep well owned by the Tangier Administration. In order to ensure an adequate supply, it was necessary to install pumping facilities and more than a mile of cast iron pipe.

Operations

Communications between Tangier and New York are conducted over four sets of four-channel send/receive electronic time-division multiplex equipment. The five-unit teletype system is employed, with an operating speed of 60 words per minute. In addition to the time-division equipment, there is a four-channel send/receive frequency-division multiplex system which is operated in conjunction with single-sideband transmitting and receiving equipment. Except for short maintenance periods, the multiplex equipment is kept in continuous operation. A five-unit "solo" printer channel is used for the exchange of information and instructions between the operating personnel in New York and Tangier.

Most of the traffic between Tangier and the cities of Europe and the East is in the form of five-unit teleprinter signals.[4] At Tangier, the received signals from the first leg of the circuit are punched on a tape. They are then read off the tape and fed into the second leg of the circuit. For the few remaining circuits which still employ Morse signals, a rapid system has been developed for converting five-unit teletype signals into Morse so as to minimize conversion delays.

The volume of traffic between New York and certain European cities is such that multiplex channels are being planned for use between Tangier and the cities in question. A set of four-channel time-division electronic multiplex equipment is already in use between Tangier and London. On this circuit, the aggregate signal is relayed—that is, the signal is received at Tangier, demodulated, regenerated, and re-transmitted on another frequency. This method has the advantage that both noise and distortion are eliminated. Extensive use of this technique in the future is indicated.

For leased-channel services between New York and several cities in Europe, five-unit teletype single-channel signals are relayed automatically. A regenerative telegraph repeater unit is used for each such channel at the output of the multiplex unit. This serves to restore the signals as nearly as possible to their original form prior to retransmission.

On occasion, Morse signals have also been automatically relayed. The signal is demodulated and then applied to a keying device which modulates the relay transmitter. This method has the disadvantage that both noise and distortion are relayed along with the signal, but a minimum of equipment is required at Tangier.

Receiving Equipment

The receivers employed at Tangier include twenty triple-diversity receivers,[5] nine dual-diversity receivers, and one triple-diversity single-

[4] S. Sparks and R. G. Kreer, "Tape Relay System for Radiotelegraph Operation," *RCA Review*, Vol. VIII, pp. 393-426, September, 1947.

[5] J. B. Moore, "Recent Developments in Diversity Receiving Equipment," *RCA Review*, Vol. II, pp. 94-116, July, 1937.

sideband receiver. The last is used in conjunction with the frequency-division multiplex equipment. Each of the receivers is equipped with an antenna patching panel so that it may be connected to any of the numerous receiving antennas. In addition, each receiver has an adapter for receiving frequency-shift telegraph signals. The frequency-shift system of keying has notable advantages over the off/on system,[6] and is used on nearly all of the signals relayed through Tangier. Figure 6 is an interior view of the receiving station.

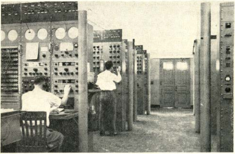

Fig. 6—Tangier receiving station. The control center is at the left.

Rhombic receiving antennas are used almost exclusively. The location of the 22 rhombics now in use or nearing completion can be seen in Figure 4. The large number of antennas required is due to the wide band of frequencies which must be covered (4 to 22 megacycles), the directivity requirements, and the need for space diversity.

Ten of the antennas are in the form of five dual units. Each unit employs four masts to support two rhombic antennas. One of the pairs is for a "day" frequency, and the other for a "night" frequency, connected so that both can be used simultaneously. The night frequency antenna is mounted at the top of the masts, and the day frequency antenna at approximately 2/3 of the mean height of the night antenna. The remaining twelve rhombics are single units. The distribution of the antennas, in terms of direction, is as follows:

[6] H. O. Peterson, J. B. Atwood, H. E. Goldstine, G. E. Hansell, and R. E. Schock, "Observations and Comparisons on Radiotelegraph Signalling by Frequency Shift and On/Off Keying," *RCA Review*, Vol. VII, pp. 11-31, March, 1946.

4 "night" antennas for New York
5 "day" antennas for New York
1 "night" antenna for the Middle East
3 general purpose antennas for the Middle East
3 general purpose antennas for the Near East
6 general purpose antennas for Middle, North, and Far Northern Europe.

In addition to the rhombics, there are several dipole and 2 experimental V-type antennas.

All of the rhombics are of standard design. Four-wire transmission lines[1] are used to carry the signals to the antenna line termination structure adjacent to the receiver building. From there two-wire lines pass through plate glass lead-in ports, into the receiving building and distribute the signals to the various receiving locations. The interior two-wire lines are transposed at intervals of approximately two feet. The characteristic impedance of each transmission line from the output end of the exponential line of a particular rhombic antenna to the input terminals of a particular receiver is maintained at approximately 200 ohms. All transmission lines are carefully balanced to ground.

Transmitting Equipment

The transmitters at Tangier are housed in two adjacent buildings with a combined floor area of 5700 square feet. Some of the transmitters may be seen in Figure 7. There are a total of 25 transmitters as follows:

8 15-kilowatt transmitters
5 10-kilowatt transmitters
4 5-kilowatt transmitters
1 3-kilowatt transmitter
2 2-kilowatt transmitters
5 1-kilowatt transmitters

Either frequency-shift or on/off keying may be used on each transmitter. When using frequency-shift keying, a quartz crystal oscillator unit is employed to hold the transmitter frequency constant.

Twenty-six transmitting antennas are employed, all of which are rhombics. Four "day frequency" and four "night frequency" antennas are directed toward New York, twelve antennas are directed toward cities in Europe, five toward points in the Near and Middle East, and one toward Capetown.

Radio-frequency power from the transmitters is carried by two-wire balanced transmissions through glass lead-in ports to a central-transmission-line cross-connect frame outside of the main transmitter building. Two-wire open transmission lines lead from this frame to the main outdoor transmission-line trunks. The lines for the individual antennas branch off from the main trunk. The outdoor transmission lines are supported by wooden poles.

Fig. 7—Interior view of the transmitting station.

Relaying Radiophoto and Radiotelephone Signals

While the facilities at Tangier were installed primarily for the purpose of relaying message traffic and leased channel services, they have, on occasion, also been used to relay radiophoto and radiotelephone signals. In the case of radiophoto, complete control is exercised from the two terminals involved, the facilities at Tangier being simply a means of linking together the two space paths. Voice circuits are used to send operating instructions. Good results have been obtained in relaying signals to and from points in North Europe, and the Near and Middle East. Figure 8 shows a picture received in New York from Helsinki via Tangier. This was sent during the 1952 Olympic Games at a time when it was not possible to send a satisfactory picture over the direct circuit. Radiotelephone signals can be relayed in the same manner as radiophoto signals.

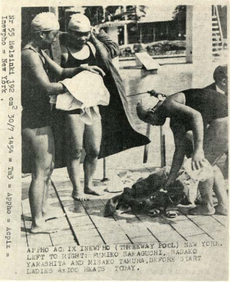

Fig. 8—Photoradio picture relayed to New York via Tangier.

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