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The AR6A Single-Sideband Microwave Radio System:

Prologue

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The AR6A Single-Sideband Amplitude Modulation (SSBAM) Transmission System makes very efficient use of the radio spectrum by transmitting 6000 message circuits in a 29.65-MHz radio channel. This capability is achieved by maintaining a tighter frequency spacing of the multiplexed mastergroup signals and by discarding redundant sideband signals before transmission over the radio path. The AR6A System can provide a maximum capacity of 42,000 message circuits for the 6-GHz portion of the radio network when all eight channels are utilized. This capability, combined with the alternate use of the 4-GHz spectrum for message or digital circuits, provides the proper mix of network capability choices. This introduction gives an overview of the AR6A System and a brief history of single-sideband evolvement in the Bell System. It also is a prologue to the papers in this volume, which describe some of the specifics of the system design.

I. INTRODUCTION

On January 12, 1981, the first AR6A† Microwave Radio System was placed in service between Hillsboro, Missouri, and La Cygne, Kansas. This event marked the first application of single-sideband transmis-

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† The AR6A designation represents Amplitude Modulation Radio at 6 GHz for the initial (A) version of the system.

sion to the Bell System long-haul microwave radio network. The AR6A System is designed for use in the 6-GHz common carrier band and can provide a route capacity of 42,000 high-quality, 4-kHz, two-way message circuits when all radio channels in the 6-GHz band have been equipped (i.e., one protection and seven service channels). If TD radio operating in the 4-GHz band is used on the same route at 1800 message circuits per radio channel, the combined route capacity is an impressive 61,800 message circuits.

II. EVOLUTION OF LONG-HAUL RADIO

The evolution of the Bell System long-haul radio network is outlined in Table I; in 31 years the radio channel capacity has been increased by a factor of 12.5 and the route capacity by a factor of 25.75. The ubiquitous TD-2 System was placed in service in 1950 and had a channel capacity of 480 message circuits with a maximum capability of five service channels in the 4-GHz band. In 1954 the circuit loading was increased to 600 message circuits per radio channel, and in 1959 the route capacity was further extended through the use of interstitial radio channels to provide a total of ten service channels. The deployment of TH-1 in the 6-GHz band in 1961 expanded the route capacity by 10,800 circuits to a total of 16,800 message circuits; the advent of

Table I—Evolution of long-haul radio capacities

System/Channel Capacity	Initial Availability	Protection Configuration (Protection × Service)	Route Capacity in Message Circuits
TD/480	1950	1 × 5*	2400
TD/600	1953	1 × 5	3000
TD/600	1959	2 × 10	6000
TD/600 + TH/1800	1961	2 × 10 2 × 6	16,800
TD/1200 + TH/1800	1968	2 × 10 2 × 6	22,800
TD/1500† + TH/1800†	1973	2 × 18	28,800
TD/1800†,‡ + TH/2400†	1979	2 × 18	36,000
TD/1800†,‡ + AR 6/6000	1981	1 × 11 1 × 7	61,800

* Automatic protection on the basis of one protection channel for five service channels (1 × 5) was not available until 1953; five service channels are used here for consistency in comparing route capacities.
† Each channel also can be equipped with a 1.544-Mb/s system.
‡ The channel alternately can be used to provide 20-Mb/s capability or (beginning in 1983) 45-Mb/s capability.

TD-3 in 1968, with a capacity of 1200 circuits per radio channel, increased the route capacity by an additional 6000 circuits. By 1973, the use of crossband protection switching systems and 1500-circuit loading on TD provided a radio route capacity of 28,800 circuits. Six years later, the circuit loadings of both TD and TH had been increased to 1800 and 2400 circuits, respectively, to give a capability of 36,000 circuits for a fully loaded radio route.

In parallel, the radio systems have grown in digital transmission capability to match network needs. In 1974 data-under-voice capability of 1.544 Mb/s was added to each FM radio channel. The alternate use of a TD-2 radio channel to provide 20-Mb/s capacity was first available in 1979, and an upgrade to 45-Mb/s capacity was provided in 1983.

Even with this capacity some radio routes were expected to be filled by the mid-1980s, and meeting additional growth needs would have required building parallel radio routes or providing some other new facility for relief. It was expected that some of the new radio routes would be difficult to engineer because of radio frequency interference encountered at radio station junctions in the existing radio network. The availability of AR6A in 1981 increased the long-haul radio route capacity to 61,800 circuits and postponed the time when new radio routes would need to be constructed, which in turn postponed the initial capital investment required for land, buildings, towers, and associated station equipment.

III. AR6A SYSTEM FEATURES

The AR6A System allows for orderly growth in the existing radio network, since it uses the same frequency plan as TH-3 and can be used for conversion of TH routes as well as for additions to existing TD routes. The radio equipment is designed to be installed in existing radio stations and shares the use of the radio towers, antennas, common waveguide runs, power plant, and alarm telemetry systems. Additional space-diversity antennas are required over those used on existing FM routes because the single-sideband signal is more susceptible to the effects of multipath fading.

The AR6A System is designed to meet a two-way outage objective of 0.02 percent and a radio channel dynamic-amplitude-misalignment objective of 2 dB or less for 99.9 percent of the time. For a 4000-mile route length, the noise objective is 40 dBrnc0. The system meets these objectives by the appropriate use of space-diversity reception and dynamic equalization in conjunction with a single-channel frequency-diversity protection system.

In meeting intermodulation noise objectives the multiplex, protection, and radio equipment were designed to linearity requirements far more stringent than those of previous radio systems. Of particular note is the AR6A transmitter-receiver (TR)* unit that has a linearity that is more than 30 dB better than the comparable TH-3 TR unit. This is achieved by the use of ultralinear semiconductor devices in the intermediate frequency circuits and predistortion in the transmitter to improve the linearity of the frequency converter and traveling-wave-tube amplifier combination.

The frequency stability required for AR6A is much tighter than that for FM systems (typically by a factor of about 25). This stability allows equalizer pilots to be selected by narrowband crystal filters and reduces the frequency range over which the receiving multiplex terminal must operate.

The AR6A System uses microprocessor-controlled maintenance and surveillance methods to monitor system performance and to isolate troubles to a specific station on a radio route. Automated testing is performed under the control of a central minicomputer at access points provided in both the multiplex and the protection switching equipment. Both in-service and out-of-service testing capabilities are provided with special stress-testing features implemented at radio repeater locations for use in trouble isolation and diagnosis. The computer-controlled measurement system is designated "Transmission Surveillance System—Radio" and is described in detail in this issue of the *Journal*.

IV. SINGLE-SIDEBAND HISTORY

In the late 1960s, detailed system studies were performed by A. J. Giger to define linearity requirements for radio repeaters (TR units) for long-haul single-sideband transmission. Several methods were recommended for achieving the necessary transmitter performance. Subsequently, experiments were performed in the early 1970s with feedforward microwave techniques to improve the linearity of traveling-wave-tube amplifiers, the most difficult challenge in achieving the radio transmitter intermodulation noise requirement. The success of these experiments led to addressing the problems of overall repeater linearity, equalization for multipath fading effects, and the effects of interference when used in the existing FM radio network.

Studies were performed to obtain a better understanding of traveling-wave-tube distortion, and this resulted in the use of predistortion to meet transmitter linearity requirements. Additional field data were gathered on multipath fading, and these data were a key ingredient in achieving a simplified dynamic equalization design. Supporting studies of a subjective nature also were conducted to provide more detailed

* Acronyms and abbreviations used in the text are defined at the back of this *Journal*.

definitions of tone and crosstalk annoyance objectives when Single-Sideband Amplitude Modulation (SSBAM) was used in the radio network; the frequency control plan and the intermediate frequency (IF) filter design were chosen to meet these objectives. The adequacy of the methods for linearization, equalization, and interference control were established by a field test performed in the 4-GHz network in 1974 and early 1975.

Detailed system design of AR6A for the 6-GHz network started in 1975, and in 1979 a complete system was installed on a 6-hop radio route from Hillsboro, Missouri, to Windsor, Missouri. All subsystems of AR6A were tested and evaluated on this 177-mile route, and system verification testing was completed on June 14, 1980. This route then was extended by three radio hops (71 miles) to La Cygne, Kansas, and became the first single-sideband amplitude modulation route to be placed in commercial service on January 12, 1981.

V. ACKNOWLEDGMENTS

The feasibility demonstration of SSBAM transmission on the long-haul 4-GHz radio network in 1974–1975 was the culmination of the efforts of many people in different organizations throughout Bell Laboratories. The realization of AR6A for the 6-GHz network was the result of the dedicated efforts of many organizations at Bell Laboratories working with Western Electric and in close concert with AT&T Communications. Technology foundations were provided by the TD, TH, and L5 Systems and these were augmented by advances in filter, network, and device designs, as well as the effective use of the many computational and measurement facilities available at Bell Laboratories. The authors of this volume express their appreciation to all those who have contributed to the ultimate attainment of SSBAM transmission on the long-haul radio network.

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