64-QAM DIGITALIZATION OF AN ANALOGUE MICROWAVE RADIO NETWORK

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ABSTRACT

With the emergence of new high capacity digital services, new modern digital networks are necessary to satisfy customer applications. However, the task is to provide digital connectivity that gives the best performance at the least cost. One way is accomplish this is to retain as much analogue equipment as possible. The TD-90 system, described here, utilizes existing long distance analogue microwave radio and economically converts it to high performance, high capacity, digital radio by application of innovative technology and careful route planning.

INTRODUCTION

The TD-90 microwave radio system is a high performance, 90Mb/s, 64 QAM, digital transmission system created by modifying and augmenting already in-place TD-2 and TD-3D analogue radio systems. Both economical implementation and excellent performance have been achieved by utilizing a system architecture that is based upon reuse of existing radio equipment while incorporating both the latest 64QAM technology and new performance features.

In any digital network the use of microwave technology complements the use of lightwave technology. Microwave technology provides quality transport on backbone routes with modest growth since microwave capacity can be implemented as needed. The cost of microwave (being primarily in the electronics) can be spread out over several years. Implementing only the capacity that is needed allows a constant high fill over the entire life of the facility.

The reuse of analogue pieces is an economical means for providing high capacity digital transmission capability when in-place analogue radio already exists. AT&T Communications has already deployed 3100 microwave radio stations, Figure 1. These stations carry microwave traffic utilizing 4, 6, and 11 GHz common carrier frequency allocations, and are geographically

FIGURE 1 THE AT&T COMMUNICATIONS 4GHz ANALOGUE NETWORK

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dispersed throughout the country. Thus application of the TD-90 system provides an effective vehicle for rapid expansion of AT&Ts digital connectivity throughout the USA by converting selected portions of their 50,000 route mile in-place analogue radio network.

The new TD-90 performance features include automatic transmitter power control (ATPC), FM interference cancelation, and digital-monitoring-based maintenance at non-regenerative repeater locations. ATPC allows the system to be introduced into a congested interference environment. It controls TD-90s interference into other systems while helping the reduce the effect of interference on TD-90 during fading. The use of FM interference cancelers increase the TD-90 signal to FM interference ratio substantially. Digital-monitoring-based maintenance at non-regenerative repeater locations allows maintenance decisions to be made remotely that are based on actual digital performance. This saves time and improves overall performance.

This paper provides a technology overview, a description of the new performance features, route and performance engineering considerations, and reports on the excellent performance of the initial 500 mile system which has been in service since April 1986.

TD-90 SYSTEM DEVELOPMENT

The design philosophy of the TD-90 Radio System is to reuse as much of the radio station hardware now used for analogue transmission as possible. Thus the station antennas, tower, waveguide, and channel separation networks are all reused. The radio T/R bays may be field converted for digital use by the addition of a single shelf of equipment and other minor modifications. The converted T/R bay contains new digital equipment as well as the preexisting analogue equipment, Figure 2. The digital terminal and regeneration equipment is a part of AT&T's new family of 64 QAM digital radio equipment.[1]

The system is designed in such a way that the eleven working radio channels may be used for either analogue or digital transmission. The protection channel is shared and protects all channels.

A system block diagram of an eight-hop switching section is shown in Figure 3. Regeneration of the digital signal is necessary after four hops. Maintenance is centralized using telemetry processors at the ends of a switching section, which communicate with a maintenance center over voice frequency lines. In order to isolate troubles, remotely switchable digital receivers are installed at repeater sites which do not contain unnecessary regenerators. This arrangement avoids costly unnecessary deployment of regenerators.

TD-90 TECHNOLOGY

In order to convert the analogue radio channels of the AT&T 4 GHz network for digital service, several key technological developments were required. Some of these had been used earlier, including adaptive IF slope and baseband transversal equalization, space diversity and predistortion. These will not be described here. In addition, the TD-90 System employs ATPC, forward error correction and an FM carrier interference canceler.

To meet linearity requirements, all radio bay circuits are operated at reduced signal levels during unfaded conditions. During either a down fade or an up fade the transmitter output power level is increased or decreased, respectively by ATPC. ATPC results in a system with optimal transmitted power during periods of normal propagation; degradations are avoided due to either excessive thermal noise during down fades or receiver non-linearity during upfades.[2]

Forward error correction is a feature included in the digital terminals of the TD-90 System.[3] Through its use, background errors are virtually eliminated. For radio link error rates (BER) of 10^{-8}, the signal after error correction is essentially error free (significantly better than BER = 10^{-13}). Improvements are not as dramatic for higher BER, however, significant system fade performance improvement is still obtained. For example, for uncorrected BER = 10^{-4}, the corrected BER= 10^{-6}.

Since the TD-90 Digital Radio System is being introduced into a nationwide sea of 4GHz FM-analogue signals, there are instances when FM cochannel interference is limiting, especially at junction stations. This problem is substantially reduced through the use of FM carrier interference cancelers. The canceler is designed to provide fade margin improvement in the digital link when the FM receiver of the interfering signal is colocated with the digital receiver. A sample of the FM signal is used to cancel the interference through dynamic amplitude and phase optimization. In a typical 30 dB fade situation, if the signal to interference ratio is 31 dB without the canceler, it is improved to 50 dB with the canceler. The canceler is effective over a very narrow band, and cancels only the FM carrier. However, since the FM sidebands are typically 19 dB below the carrier (for 1800 circuit loading), substantial benefit accrues by canceling only the carrier.

PERFORMANCE ENGINEERING

The typical TD-90 Route Engineering schedule is shown in Figure 4. Performance engineering of a 64 QAM microwave route requires detailed information of the operating environment. Since TD-90 is a retrofit technology, it also requires accurate information about the reusable pieceparts in addition to the environment. For this reason, the first Route Engineering activity shown is Route Qualification. This procedure consists of two types of tests. The first tests are to characterize the analogue radio bays and thus ensure their suitability for TD-90 use. If the bays are not suitable, proper action can be taken early in the process to facilitate their upgrade to the necessary level. The second tests in Route Qualification are transmission tests to quantify both the transfer function of the antenna system/transmission path and the interference environment. Cancelers can be ordered, antenna blinders can be installed, and space diversity can be added if any deficiencies are discovered early in the process. That is the key to quality performance. The information obtained in Route Qualification is then used to engineer the route.

The major detriment to digital radio is multipath fading.[4] Knowing the interference environment allows detailed outage calculations to be made and the proper amount of space and frequency diversity can be added using the concept of the composite fade margin.[5] [6] [7] After the route is engineered, the system can be ordered, the route can be upgraded as needed, the system can be installed, and finally, service can begin. A transmission outage occurs when the bit-error-rate (BER) exceeds 10^{-3}. The availability objective for long haul facilities has traditionally been an annual all cause, two way transmission outage of less than .02% of the time on a 4000 mi. route. The distance prorated, one-way objective for outage is .8 seconds/year/mile. Routes are typically engineered to meet this objective.

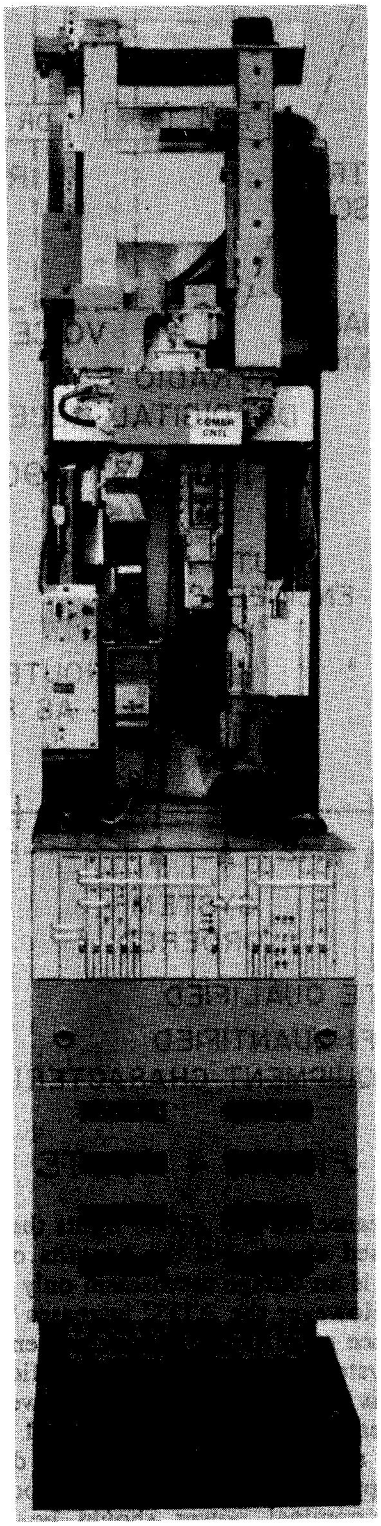

FIGURE 2 TYPICAL TD ANALOGUE RADIO CONVERTED TO TD90

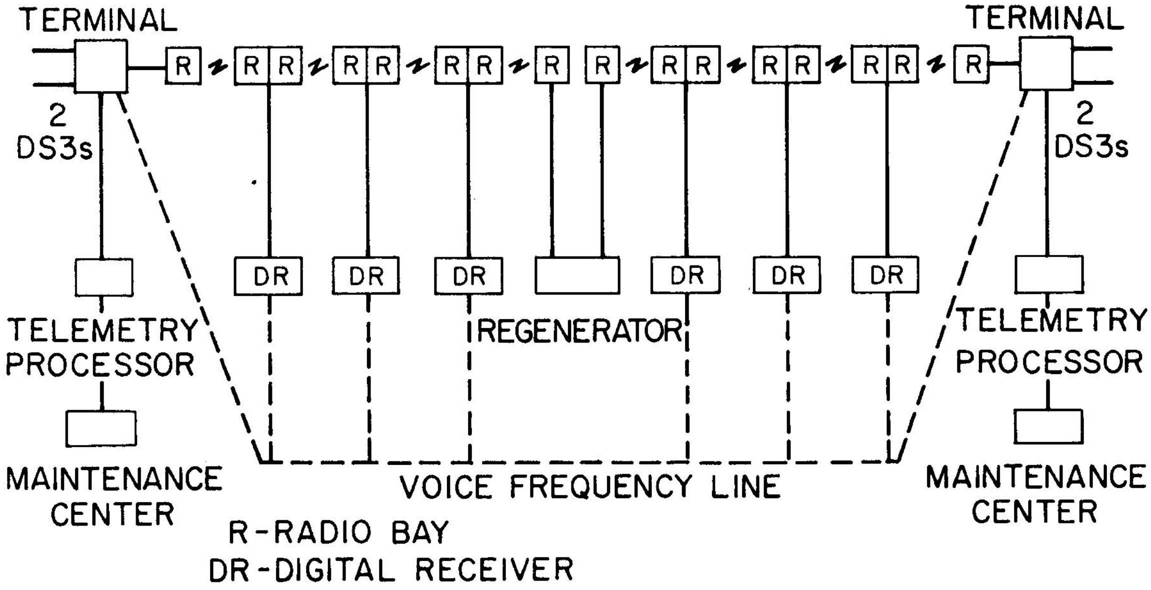

FIGURE 3 TD90 ROUTE BLOCK DIAGRAM

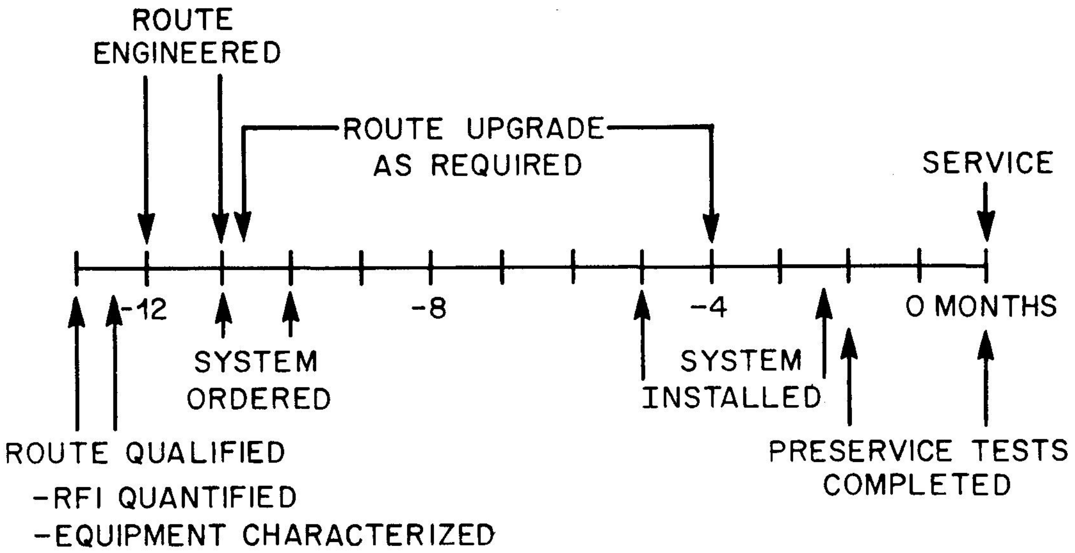

FIGURE 4 ROUTE ENGINEERING SCHEDULE

The use of cancelers and ATPC fights the effect of interference. The benefits of cancelers has been discussed above, but the benefits of ATPC need further elaboration. In digital radio, interference is an outage mechanism only during fading, when the signal to interference ratio is degraded. However the ATPC increases the system power during this time, keeping the signal to interference ratio fixed. Proper hop engineering requires maximum power to be transmitted when the system encounters fades sufficient to cause outage. Thus the ATPC system is a system that is transmitting maximum power when it counts. Because of this, when coordinating the interference into a system equipped with ATPC, the ATPC maximum power should be used. Thus a benefit of more than 10 dB is achieved when coordinating interference into a system equipped with ATPC. When coordinating interference from a system equipped with ATPC, the nominal power should be used. This is because when the hop is properly engineered, the amount of time that the power differs from nominal power conforms to the existing long and short term interference objectives. Thus the use of ATPC produces a win/win situation for both fixed power and ATPC systems, they both reap the benefits of a better interference environment.

INITIAL APPLICATION

The first installation of TD90 was turned up for service in April 1986. The total route was from White Plains, New York to Cleveland, Ohio, Figure 5. This amounts to a 750 route miles, and is a 10 switch section implementation, with some sections having 4 hops before regeneration.

Beginning in November 1985, Spindle Hill to Albany was put into service as a first office application. This four hop switch section was then tested until the middle of January. A DS-3 circuit (45 MB/s) circuit was fed in Spindle Hill with a pseudo-random digital signal and was monitored in Albany. An identical arrangement was implemented in the reverse direction. This amounts to a 93 mile circuit. The total number of 10^{-3} and 10^{-6} BER seconds before error correction from midnight to 8:00 AM from November 7, 1986 to January 17, 1986 is shown in Figure 6. This is for one of four of the DS-3s on the route, the others exhibited similar or better performance.

In terms of total errored seconds, there were only 13 errored seconds which amounts to better than 99.999% error free seconds. Of the 13 errored seconds, twelve were severely errored (BER$>10^{-3}$). In total 87% of the days monitored were error free. This easily meets all digital service objectives for error free seconds.

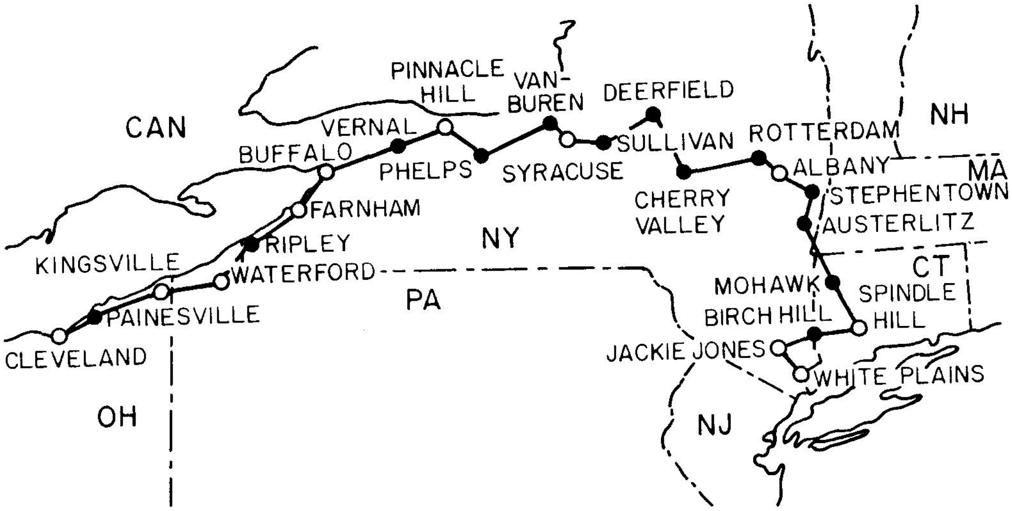

FIGURE 5 TD90 FIRST INSTALLATION

TD90 FOA PERFORMANCE
11-7-85 - 1-17-86

TOTAL TEST DAYS	62
ERROR-FREE DAYS	54 (87%)
DAYS WITH 10^{-6} SECONDS	8
DAYS WITH 10^{-3} SECONDS	8
10^{-6} SECONDS	13
10^{-3} SECONDS	12
% ERROR-FREE SECONDS	99.9998

FIGURE 6 SUMMARY OF PERFORMANCE ON FIRST TD90 SECTION AVAILABLE FOR TESTING

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