IMPLEMENTATION OF A MILITARY DIGITAL MICROWAVE SYSTEM

G. Lippencott, H. van Gelder, P. Villasenor

ABSTRACT

A discussion on the Army FKV 192 channel digital microwave system now operational. First such system designed for military operation. Includes: 1) System description; 2) engineering criteria; 3) maintenance philosophy; 4) technical problems encountered; and 5) long-term performance assessment.

I. SYSTEM DESCRIPTION

The Frankfurt-Koenigstuhl-Vaihingen (FKV) project represents the initial step by the Department of Defense into long-haul digital communications. While multi-media; the existing Defense Communications System (DCS) is primarily an analog system. The FKV links provide high quality encrypted telecommunications service for both voice and data traffic between key DCS stations located in the Federal Republic of Germany.

The decision to implement a digital system was made only after a series of theoretical studies and hardware tests indicated that there was a high probability of success in meeting DCS transmission standards for reliability and quality and the feasibility of digitizing the entire DCS incrementally. The system is composed of five microwave line-of-sight links (8 GHz range) utilizing Pulse Code Modulation/Time Division Multiplex (PCM/TDM) techniques applied to FM radios modified for digital application. This system provides 192 channels (nominal 4 kHz) in a 14 MHz bandwidth limiting, modulation technique.

The major items of equipment utilized in this system are:

a. TSEC/CY-104 which is essentially a D2 channel bank first level multiplexer and which provides the analog-to-digital conversion and bulk encryption. This unit, utilizing 8 bit encoding, multiplexes 24 duplex telephone office trunks (both voice and signaling) into a single 1.544 megabit (T1) bipolar pulse stream. The T1 data stream is then encrypted.

b. T1WB1 which is an alternative first level multiplexer used for data inputs. The terminal time division multiplexes up to eight channels of 0-50 kb/s data into a single T1 bipolar pulse stream utilizing transitional encoding.

c. A second level multiplexer for up to eight non-synchronous T1 inputs into a 12.6 mb/s serial bit stream, which is then filtered to produce a three level partial response signal.

d. AN/FRC-162 radio. Operation is in the 8 GHz range with an output power of 1 watt in a space diversity configuration. The modification allows operation with a three level partial response TDM baseband signal at a 12.6 mb/s rate. The radio also transmits an 8.5 MHz pilot and a 300 Hz to 8 kHz maintenance coordination channel translated above the TDM baseband.

II. ENGINEERING CRITERIA

Existing military analog standards were used as design guides. The only existing criteria for digital transmissions were the requirements for low and medium speed data. This established a Bit Error Rate (BER) of 1×10^{-5} (one error per 100,000 bits) user to user and 1×10^{-6} tech control to tech control.

Since this BER would provide satisfactory service to the user after the influence of the outside plant this was the BER established for the point of digital to analog transition (T1 line) in the FKV system. A hypothetical 1000 nautical mile system was postulated. An allocation of 1 error in 10^9 bits for each nautical mile of the system results. Based on FKV system length and the low probability that more than one link will be at threshold simultaneously a link design error rate was established as 7×10^{-8} for each link. For test purposes therefore the five link combination of FKV would yield a range of error probabilities of 7 errors in 10^8 bits to 3.5 errors in 10^7 bits.

Utilizing the link bit error rate of 7×10^{-8} and the experimentally determined RSL versus BER curve for the equipment configuration of FKV, the threshold and system gain were established. Links were designed utilizing the path loss predictions of NBS Technical Note No. 101 (revised) and the above determined system gain to meet a time availability of 99.99% with a 95% statistical confidence factor.

Computer simulation showed that there was a high probability that regeneration would not be required at repeater sites on nominal length links with one repeater. Regeneration was included at one repeater to provide for a future drop-and-insert requirement.

Two criteria for the performance of the digital multiplexers are bit count integrity (BCI) and jitter. Mean time to loss of BCI was established as greater than 24 hours. A probabilistic model based on the error characteristics of the equipment showed that even if the multiplex links operated at threshold for 24 consecutive hours, the probability of loss of BCI was negligible.

The requirement for jitter was established as 1/4 of a bit interval peak departure from nominal sampling time. Performance of an asynchronous digital multiplexer is characterized by the jitter which may be additive in a multi-link system. Satisfactory jitter performance was observed during verification tests, even when the number of links was expanded to 16.

One area of uncertainty is the impact of short deep fades characterized by a Rayleigh distribution. For an FM analog system, when carrier to noise versus signal to noise is plotted a near linear relationship is evident to the point near threshold. Thus, performance exhibits a "graceful" slide to threshold. However, for a digital system, the plot of signal to noise ratio versus BER in the same region shows each dB less signal increases the BER by an order of magnitude. Complete loss of data occurs relatively abruptly. Fades lasting in duration for only milli- or microseconds will have a severe impact on the error rate and establish the link BER. Rayleigh fading will increase BER to a value coincident with the lowest signal level being received. Consequently, the error threshold is highly dynamic in nature. In actual system operation, BER's have been observed moving in a range from 10^{-3} to 10^{-8} or better without clear correlation to the apparent average RSL, as measured by monitoring the AGC voltage.

The problem thus becomes one of reliably predicting and accurately measuring performance. The broad outline of the solution appears to be:

a. Predicted performance will be based on existing path loss calculation methods modified to adequately describe the dynamic nature of the threshold and provide an acceptable level of statistical confidence in the predictions.

b. Actual performance will be measured on a probabilistic basis. A statistically valid correlation between BER's and RSL's will have to be developed. In addition, it appears that the RSL should be monitored at the IF strip.

III. MAINTENANCE PHILOSOPHY

The equipment configuration for this system was selected after thorough study of operational and maintenance concepts.[1] All of the operational and maintenance requirements center on system availability. Availability was calculated in two ways, station and system availability.

Six alternative multiplex configurations, each providing a different degree of multiplex redundancy, were synthesized. The DCS design objective is station availability of 99.99%, equivalent to a maximum total outage time of 53 minutes per year. The model selected (no redundancy for the first level multiplexer) would satisfy this requirement.

It was determined that the repairability of the digital portion of the system has a mean of five minutes. Similarly, it was determined that restoral of all circuits, on a first level multiplex using redundant standby equipment, would require not less than six minutes. Further, the failed portion of the system would, in most cases, consist of a single circuit. Thus any attempt to restore circuits before repairing failed equipment would lengthen the outage and put additional circuits out of service. Hence a "repair to restore" maintenance philosophy is being used. This is a radical departure from the existing military communications philosophy of "restore to repair," then fixing off-line equipment.

IV. TECHNICAL PROBLEMS ENCOUNTERED

As described previously the introduction of a digital system into the DCS resulted in the development of new engineering criteria. When the FKV system was installed unforeseen problem areas became apparent.

The single most important fact that was learned is that FKV type digital systems are susceptible to degradation from sources other than those affecting modern analog systems. An analog system in the same environment might meet communications requirements with associated system losses, noise and distortion appearing as noticeable, but allowable, channel noise. A digital system may not provide acceptable communications since degradation can have a severe impact on BER and framing of the digital multiplexers.

During initial testing of the FKV system it was discovered that this susceptibility was adversely effecting performance. There was no single major source of degradation but, rather, the degradation resulted from minor losses and interference introduced at various stages in the system. Areas of degradation were:

a. Improper isolation of power from signal grounds and the existence of common impedances resulted in interference being induced into the signal path causing bit errors by interfering directly with the clock recovery circuits in the second level multiplexer.

b. The length of interconnect cable at the T1 or baseband rates was found to be critical in this digital system. The signal is degraded through attenuation and amplitude distortion. In addition, spurious signals are inductively coupled into cables and cause additional interference. Figure 1 shows the losses in the T1 (1.544 mb/s line utilizing twinaxial cable.

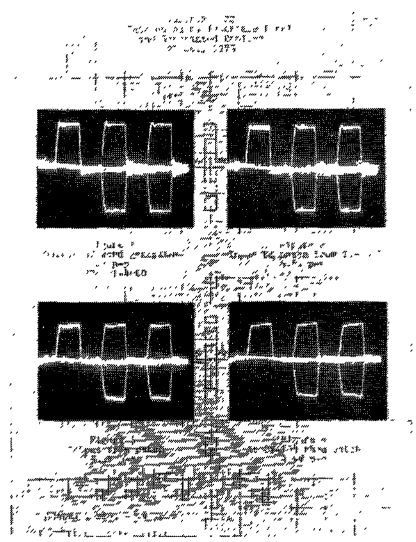

FIGURE 1

This particular test uncovered a critical problem, since the minimum input to the multiplex equipment is approximately 5.0 V p-p. The objective is to minimize cable lengths; hence, collocation as much as possible of the digital multiplex and radio equipment for each link with technical control becomes a prime consideration.

c. Unless the operational requirements for reroute, restoration and system monitoring are overriding, centrally located patch and test facilities above audio level should be avoided in the interests of reducing cable losses and noise induction. Figure 2 shows the pickup through a patch panel.

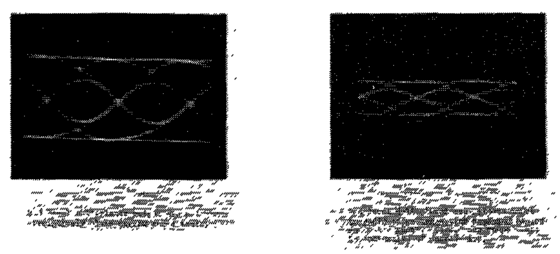

FIGURE 2

In spite of a scale change, the noise is evident by thicker, blurred lines in these eye patterns. Pickup can be detected from the distortion in the top and bottom lines of the second pattern. If high frequency patch panels are provided, losses and distortion are prime considerations governing their location.

d. The cables used in this system (coax, twinax, triax) were found to need rigorous installation techniques. Improper grounding of shields or improper installation of connectors were found to be a source of degradation. The patch panel shown in figure 3 is a typical example of lack of attention to detail.

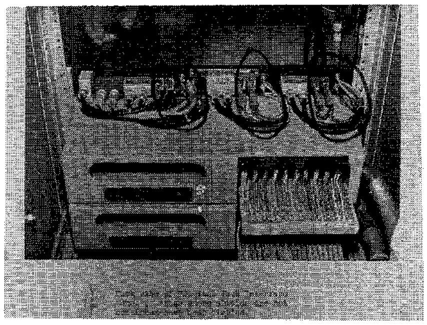

FIGURE 3

Monitor jacks were installed using unshielded jack designs. Unfortunately, the unshielded stubs were susceptible to EMI causing system degradation.

In short, this susceptibility of a digital system to degradation makes it necessary from an engineering point of view to minimize fixed losses associated with equipment interfaces and cabling.

V. LONG-TERM PERFORMANCE ASSESSMENT

One of the major objectives in implementing this system is to perform an operational evaluation of the system; the hardware, the software, and the people. The FKV system is being activated as a pilot system. It will provide an opportunity to assess system components for the Department of Defense. Therefore, The Institute for Telecommunications Sciences (ITS) has developed and implemented a semi-automated data collection and reduction system completely transparent to the transmission system to monitor the significant operational and concomitant technical parameters of the FKV digital system for approximately one year. The purpose of this study is to:

a. Obtain engineering information that will prevent costly under-or-overbuilds.

b. Determine if there are any parameters that can be measured while the system is in service that will accurately assess the quality of transmission of the information traversing it and therefore permit trending of the system status.

c. Determine the stability and reliability of PCM/TDM systems.

Data acquisition will be performed by four minicomputers with the system evaluated on an end-to-end basis in both directions as well as on the individual links, although not necessarily in the same direction. The intent is to monitor as many test points as possible within practical limitations in order to surface and identify the more salient parameters that may be most indicative of system performance.

An important part of this measurement program is the data on human operations and reactions. The teletype at each site will be used by the on-duty maintenance personnel to record what (in their opinion) happened, why they took the actions that were automatically logged, etc.

As of this writing, there is insufficient data to present for publication. It is the intent of the Army to publish the results of these investigations in the open literature.

VI. CONCLUSION

As can be seen from the above, the US Army's first strategic digital microwave system was not without its implementation problems. While the technology and individual hardware items were available, system operation depended on new criteria and faced unexpected problems.

In chronological order, the following problems were resolved. An analogy was made with the existing FDM system and BER for this system was set at 7×10^{-8} per link and 3.5×10^{-7} with an upper limit of five links in tandem. A bandwidth limiting modulation technique was selected so that the 192 VF channels would fit in the 14000F9 frequency allocation. After an availability analysis, system hardware requirements were established to provide a hot-standby 2nd level multiplexer.

Analysis showed theoretical link and station availabilities meeting the DCS criteria. Projected outages are 38-45 minutes per year, however the majority of the outages will only affect one channel. Due to the low expected outage rate and the short mean repair time, a new (for the DCS) repair philosophy was adopted, repair to restore. The radio and multiplex sites are designed for unmanned operation.

Once installation began, a number of additional problems surfaced. These were a combination of faults centering on equipment susceptibility to noise and high station noise levels. It was found that the digital equipment, was sensitive to noise introduced on the ground system and the power lines. This appears to be a generic characteristic of the digital equipment of the type utilized in this project.

The FKV system is now operational. To determine how well the system works and to see whether there are any people problems with the system, an operational evaluation using on-line minicomputers is being made. While it appears that the customers are satisfied with the performance of this new system it is too soon to tell whether further personnel training is required or whether the design criteria are being met.

REFERENCE

[1]ROSENBLATT, S. J. "Consideration for DCS Digital Links," Signal, November/December 1974, pg 35-39.