TELEMETRY TRANSMISSION USING INVERSE MULTIPLEXING AND ASYNCHRONOUS TRANSFER MODE (ATM)

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Abstract

The growing need to transmit larger telemetry streams from the receiving site to the processor location over greater distances is requiring newer and more creative techniques. This paper reports efforts to use Asynchronous Transfer Mode (ATM) technology and inverse multiplexing to provide an economical system to interface telemetry streams into the public network for reliable transmission. Cost savings are available immediately for programs that are willing to meet the synchronization criteria today. Lab testing has shown the feasibility of using cost efficient techniques for data transmission.

This document describes the investigation that is currently underway that could provide a significant change to the way telemetry data is transmitted from receiver sites to data processing sites. Instead of using dedicated lines with dedicated bandwidth regardless of the program being supported, the approach that has been tested in a lab environment would allow the dynamic allocation of bandwidth using ATM over a variety of carrier services. The combination of ATM and inverse multiplexing allows telemetry data rates above 1.5 Megabits per second (Mbps) to be transmitted over multiple T1 (1.544 Mbps) lines. Previously, the only choice when data rates exceeded 1.5 Mbps was to use an entire DS-3 (45 Mbps). Now it is possible to transmit intermediate sized data rates (1.5 to 8 Mbps) by bonding multiple T1s to provide the desired data throughput.

Keywords

ATM, Telemetry, Inverse Multiplexing, Flight Test

Introduction

The current trend in the flight test community is moving away from centralized testing into an extended range concept. Several reasons contribute to this changing environment. Unmanned Aerial Vehicles (UAVs) require large geographic areas to conduct high endurance testing and new weapons programs require specialized ranges and range instrumentation. At the same time the test areas increase in size, the telemetry bandwidths increase in rate due to advances in avionics and aerostructures. The cost of the programs is partly driven by getting the data to the engineers as efficiently as possible. As the data rates surpass the T1 data rates, the next available service from the Public Telephone Network is T3 (45 Mbps) which is typically cost prohibitive.

This paper describes efforts to investigate efficient methods of transmitting data through the Public Telephone Network to meet the extended range higher bandwidth transmission requirements. Also included in this paper is the role of Asynchronous Transfer Mode ATM in the flight test range environment.

Background

In an effort to meet the extended range requirements, alternatives are being investigated to move telemetry data of bandwidths in the 2-10 Mbps over large distances. Historically, telemetry streams have been distributed in local configurations without regard to wasted bandwidth. For instance, some of the smart multiplexers available today will transmit up to eight telemetry data streams over a T3. If only one stream, at say 2 Mbps, is required, then 43 of the 45 Mbps is not being used to carry useful data.

More than one test program has been forced to modify their test program because of the prohibitive cost of moving data between multiple ranges. The only available solution was to connect a T3 between the ranges and pay high monthly fees for the service. More affordable solutions are required to expand test capabilities of both open air and modeling and simulation testing.

Several of the requirements that must be addressed when designing a range telemetry communications system include:

- System timing
- Interfaces
- Latency
- Security

The predominant issue with moving telemetry data over the public phone company is adopting a non-standard communications technique to a heavily standards based communications system. Telemetry packages are generated using basic rules called out by Inter-Range Instrumentation Group (IRIG) guidelines and then left to the creativity of the individual instrumentation engineer to generate the data stream. The International

Telecommunications Union (ITU) is the governing body of telecommunication standards which are strictly adhered to in the public telephony services.

This paper addresses two tests using Commercial-Off-The-Shelf (COTS) equipment to determine the feasibility of more efficient data transmission techniques. The two tests use ATM and inverse multiplexing technology. The ATM technology was selected as the technology of choice due to the overwhelming support of the commercial market and the advantages of the technology in sharing bandwidth.

ATM Test

Between March and May 1997, GTE provided an OC-3c (155 Mbps) connection between Edwards AFB and NAWC-WD, China Lake and two Newbridge ATM switches for the purpose of evaluation. The testing (shown in Figure 1) included the following signal types:

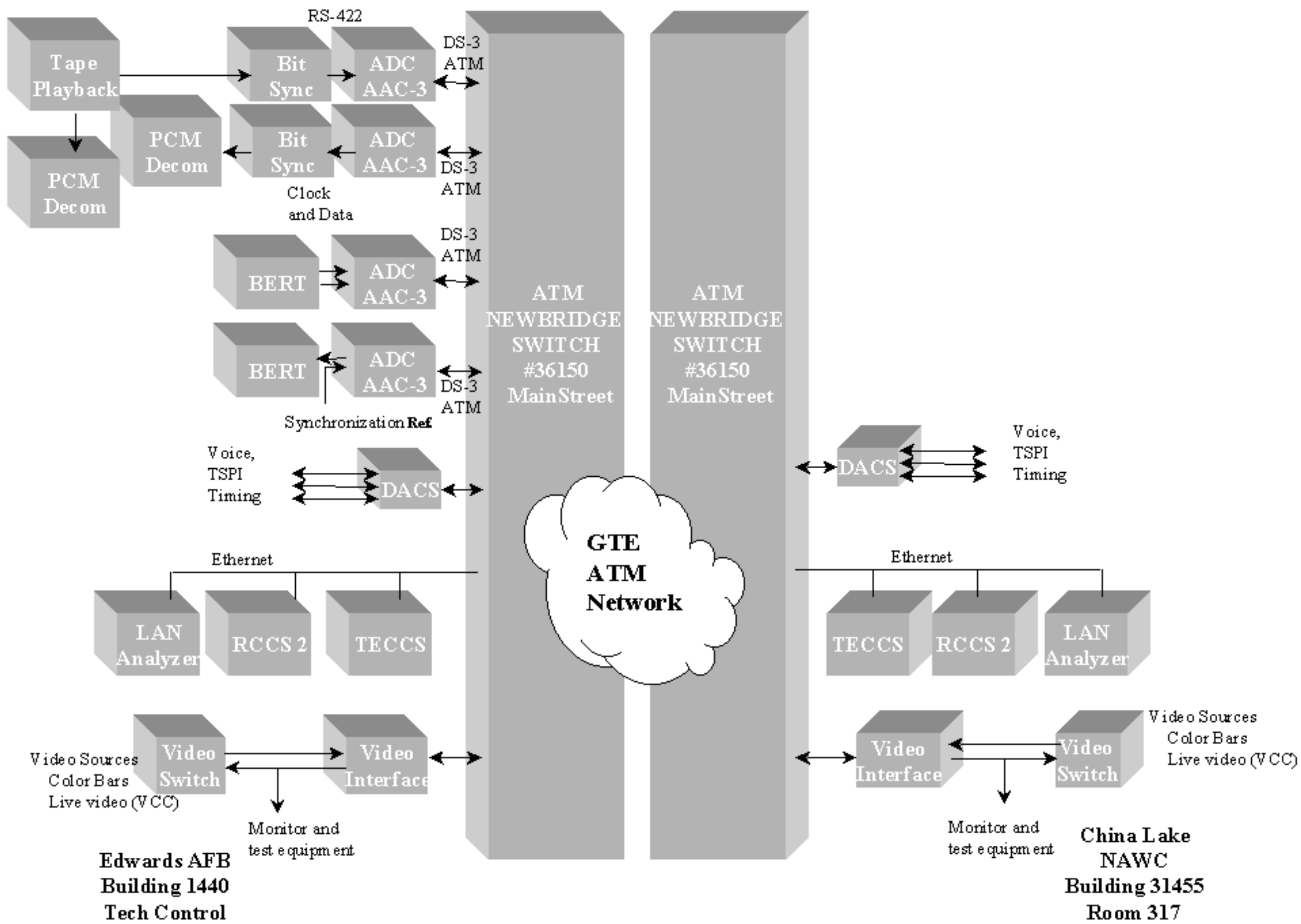
- Video
- Voice
- Time Space Position Information (TSPI)
- Timing
- Telemetry
- Ethernet

Four separate tests were run using ATM for four different types of interfaces: T1 Circuit Emulation, Video, Network, and Telemetry. For the sake of brevity only the TM tests are discussed here. Two TM tests were planned: one through a DS-3 smart multiplexer and the other TM to ATM direct. DS-3 circuit emulation cards were not available so only the TM to ATM discussion is presented.

Telemetry to ATM Direct

Two ADC Kentrox ATM Access Concentrators - 3 (AAC-3) were borrowed to test the direct translation of telemetry to ATM. The AAC-3 was connected through a T3 User Network Interface (UNI) card in the Newbridge switch. Two test approaches were used during this test: BERT and tape playback. Two types of tests were conducted using the BERT. First running the BERTs with independent clocks, then using a “manual” clock correction.

Figure 1 - Test Configuration for ATM Test



BERT with independent clocks

This test was to determine the performance of the ATM system to manage two independent clocks at the receive and transmit interfaces. Two Firebird 6000A BERTs were used to generate and receive data at equal rates and known pattern (Quasi-Random Signal Source [QRSS] was used). The AAC-3 has two timing modes on its RS-530 interface, system clocking which only provides standard telecom data rates and port clocking which provides for any data rate – as long as the clocks are synchronous. The BERTs were both set to run using internal clocks and the AAC-3s were set to port clocking.

Running the BERTs at various rates, the port speed limit of the AAC-3 was found to be between 4.2 and 4.5 Mbps. When the network elements are not synchronized and the BERTs are free running (simulating telemetry), pattern resynchronizations occur regularly. Tests were performed at three different data rates 1, 2, and 3.8 Mbps. The following table summarizes the results:

Data Rate	Start Time	Stop Time	Time between Losses Average	Time between Losses Std Dev	Number of Losses
3.8 Mbps	14:39:45 7-Apr-97	6:26:25 8-Apr-97	0:04:59	0:00:04	189
2 Mbps	12:43:33 4-Apr-97	5:41:49 7-Apr-97	0:09:31	0:02:11	402
1 Mbps	14:09:52 8-Apr-97	5:21:08 9-Apr-97	0:20:16	0:03:47	44

Table 1 - BERT Test Results for Various Data Rates, with Independent Clocks

The probable explanation for the resynchronization is the AAC-3 output buffer. This output buffer tries to run at about half full. Since the clocks are different rates, the buffer is constantly filling or emptying based on the clock relationship. When a limit of the buffer is reached, the buffer resets to the center, causing a loss of data and a momentary drop in data. When the buffer is reset to half, the data is output again and the BERTs resynchronize.

BERT with clock correction

The purpose of this test is to control the clock on the receive end of the circuit to emulate a telemetry transmission system. This configuration provides for a free running clock (in an aircraft instrumentation package) transmitting a serial data stream through a transmission system to the processors. By controlling the clock at the receive end, a corrected timing signal can be provided to the AAC-3 to gate the data out at a rate much closer to the initial clock rate, therefore keeping the receive buffer from overflowing or underflowing.

To complete this test, a measurement must first be made to determine the frequency offset of the two BERTs (or transmitter and receiver in a telemetry scenario). In practice, comparing the telemetry output rate to a rate traceable to Universal Time Coordinated/Global Positioning System (UTC/GPS) could do this. By knowing the offset, it is possible to drive the output of the AAC-3 at the rate required to keep the buffer from overflowing or underflowing.

The measurement in this case was done between the two BERTs. The “telemetry transmitter” BERT was set to internal timing while the “telemetry receiver” BERT was externally timed from the first. In this configuration, the ATM circuit appeared to run error free (as expected). The “telemetry receiver” BERT displayed the “receive frequency” compared to its internal oscillator, in this case it was 3 Hertz (Hz) over the test data rate (4.2 Mbps). An external frequency generator was then connected to the “telemetry receiver” BERT to adjust the clock to use the previously recorded frequency offset. In practice, the transmitter data rate should be compared to a very accurate reference at the “transmitting site” and a very accurate reference (i.e., GPS) used for the correction at the “receiving site.”

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TIMED      PRINT
05:20:48 11 APR 97  SITE ID      1440  BIT ERRS        0  AVG BER   0.  E-10
BER      0.  E-06  BLOCKS    38476545  BLK ERRS        0  AVG BLER  0.  E-07
PAT SLIP        0  EA SEC       57599  ERR EAS         0  EF EAS       57599
RCV FREQ   4200000  GEN FREQ   4200000  DELAY       8.0ms  PAT LOSS        4
PATL SEC        2  %PAT SEC   >99.99%  DAT LOSS        2  CLK LOSS        0
PWR LOSS        0  C-D CHA          0  ERR-SES         0  BER-SES   0.  E-11
GERR SEC        2  G EFS        57597  G %EFS     >99.99%  UNA SEC         0
AVL SEC     57599  %AVL SEC   100.00%  DEG MIN         0  %DEG MIN    0.00%
SES             2  %SES       <0.01%  ELAP SEC     57600  EMULATE       DTE
RR             ON  DM              ON  CS              ON  TM            OFF
RS            OFF  TR              ON  IF  RS-449/530/MIL
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Figure 2 - Test Equipment Printout after Test Run with Clock Reconstruction

Figure 2 shows a timed print from the receiving test set at the end of the test period. The test duration was 16 hours using the "Elapsed Seconds" field of 57,600 seconds. Notice that four pattern losses occurred and two data losses. This was due to two separate sync losses that occurred at 19:38 and 2:48 during the test period. This indicates the frequencies were offset slightly and a sync loss would probably occur every 7 hours or so.

This test supports the theory that the sync loss in the free running scenario is due to frequency offset rather than clock drift between the transmitting and receiving end of the ATM network. The ATM receive buffer will compensate for frequency drift around a center frequency or small change in magnitude over a given time period.

The results of this test were successful. This link ran error free for over 6 hours. This equates to an average bit error rate (BER) better than 10^{-10}. These results are good enough to support the telemetry requirements of the flight test community. The next step is to integrate bit synchronizers and provide an end-to-end capability between China Lake and Edwards.

Telemetry Tape Playback

After the BERT testing was completed, an attempt to run telemetry data through the system was attempted. An F-16 baseline tape was used to run data from a recorder to a bit synchronizer feeding the AAC-3. Figure 3 shows the test configuration. The test was cut short fairly quickly when the output from the tape recorder was found to drift several hundred Hz. The data rate of the test tape was 256 kbps. When measured on

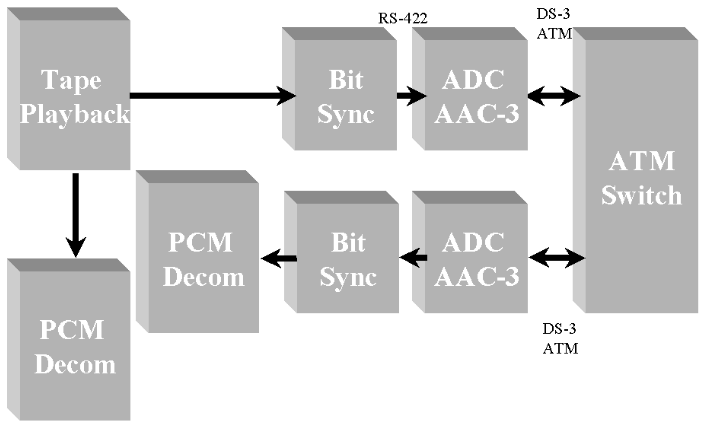

Figure 3 – Test Configuration for Telemetry Playback from Tape

test equipment, the frequency was found to drift from 255,500 to 255,900 Hz. The whole concept of reconstructing the clock externally is based on a stable reference (within a few Hz, worst case). This test setup did not work when transmitted through the ATM network. However, the decom directly connected to the output of the tape recorder kept frame sync without a problem. The decom was displaying a received frequency that was also changing several hundred Hz. This indicates that any solution for this transmission problem must meet the IRIG 106-96 specifications for clock stability.

Inverse Multiplexing

Inverse multiplexing is a technique in which larger data streams are intentionally fit into smaller data paths for error free transmission. A prime example of this is the use of Nx64 data channels for the extension of data through T1 multiplexers. In a telemetry world, where data streams are much wider, the need for bonding multiple T1s is required for a wide enough path to contain all of the data.

Several companies are currently shipping T1 inverse multiplexers, but several restrictions must be met. The typical interface to the inverse multiplexer is a High Speed Serial Interface (HSSI). The second restriction is the use of fixed data channel widths. To use the inverse muxes, the data must be an exact multiple of 1.528, for instance. This solution is not acceptable for a telemetry engineer who is responding to the needs of a customer and considering other factors for the optimization of the telemetry data cycle. Under these circumstances another solution is required, such as a device in front of the inverse mux to provide the required input. One solution that was lab tested is described below.

ATM Data Service Unit

Verilink Corporation, who also manufactures a T1 inverse multiplexer, has a solution to this interface problem with an ATM Data Service Unit (DSU). This DSU is designed to input/output a HSSI interface, perform the Segmentation and Reassembly (SAR) function and transmit the ATM cells onto a T3. The HSSI is capable of handling variable rates based on the clock input. One integration issue was to change the HSSI interface into a

Transistor to Transistor Logic (TTL) interface and output the T3 to a HSSI interface for the inverse mux.

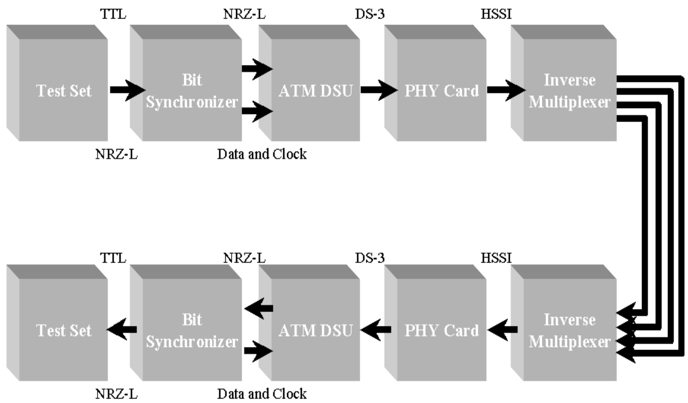

Figure 4 - Test configuration using ATM DSU and Inverse Multiplexer

Integrated Solution

The two technologies (ATM and Inverse Multiplexing) were integrated in a lab test set to simulate a telemetry stream in a lab environment as shown in Figure 4. The test was arranged in the Verilink engineering lab to see if the required interfaces could be supported. Verilink engineers bypassed the HSSI interface to an existing internal TTL interface and output the T3 to the HSSI interface required for the inverse mux. An additional card was required (Phy card in Figure 4) to convert the ATM on the T3 to HSSI. The test was a success. The same clock anomaly as described above was encountered. When a common clock was used to synchronize the transmit and receive equipment, the system worked at better than 10^{-9} BER.

During the test, data was successfully transmitted at 128 kbps to 4 Mbps. When data was attempted at 5 Mbps, data dropouts were noticed. These dropouts were expected because of the associated overhead required in this configuration. The overhead required for this system is about 30 percent: ATM has an overhead requirement of about 10 percent, T3 framing of about 1 percent, Physical Layer Convergence Protocol (PLCP) overhead of about 7 percent and an additional 9 percent for cyclic redundancy check (CRC) (1.1x1.01x1.07x1.09=1.29=29 percent overhead). It is possible to reduce the overhead. The overhead for the PLCP and the CRC are the areas where this overhead improvement would be realized. The trade-off for reduced overhead is additional latency.

The other issue of primary interest is the latency induced into the system by the transmission system. A buffer in the transmit and receive DSU causes the latency to be dependent on the rate of the input stream. The transmitting ATM DSU delays the signal by 480 bytes (~2 msec at 2 Mbps). The receiving DSU has a First-In-First-Out (FIFO) buffer to accommodate Cell Delay Variation (CDV) that is expected in ATM networks. The CDV is a product of ATM being a cell based protocol that allows shared usage of transmission lines which may have time gaps between cells and cells intended for different ports interleaved. The receive DSU maintains a 128 kilobyte FIFO to overcome the effects of CDV and overcome the effects of minor variations in the clock rate. The delay at

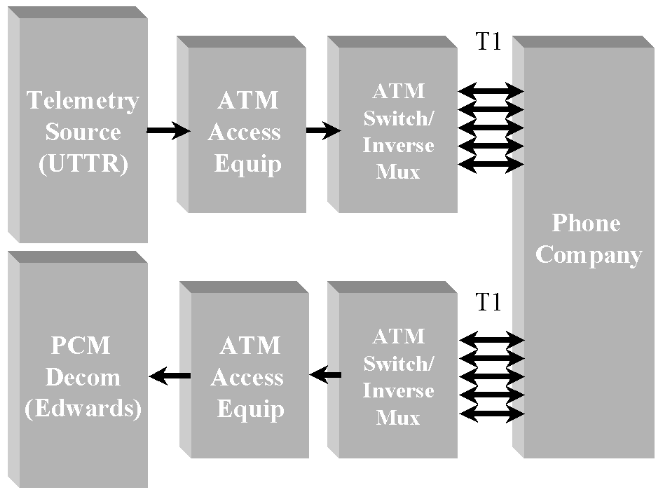

Figure 5 - Architecture for Inverse Multiplexing between UTTR and Edwards

2 Mbps for this buffer is theoretically 512 msec. The delay for each inverse multiplexer is 30 msec. For a 2 Mbps data stream the total latency induced by the transmission equipment in Figure 4 is 574 msec, not including the transmission delay.

Inverse multiplexers provide solutions to several types of range communications scenarios. Two implementations can be considered when integrating ATM in the range environment: upgrade existing systems and support of new projects. For instance, to support new missions between Hill AFB in Utah and Edwards AFB of moderate bandwidth (2-8 Mbps), inverse multiplexing is likely to be the most cost-effective approach. Figure 5 shows the architecture.

The alternative to inverse multiplexing is leasing an entire T3. The cost of the end equipment required to move data over multiple T1s, when developed, is expected to be less than the cost of equipment to move multiple streams over a T3. For carrier service in this particular case, estimates for the 5 T1 lines is $11,615 for setup charge and $16,055 monthly charge. The T3 cost is estimated at $9,930 setup charge and $30,324 monthly charge. The savings are $12,584 the first month and $14,269 every month thereafter.

The second scenario is to upgrade existing systems such as the communication path between Edwards AFB and Vandenberg AFB called “West DATS” (Data Transmission System). This system is being augmented for a channelized T-3 capability. As inputs to the M13 multiplexer, it is possible to input several channels for inverse multiplexed telemetry as shown in Figure 6. This provides a better utilization of bandwidth by not limiting the number of channels to eight, a typical number for multiplexers providing isochronous capability over a T3.

A more efficient solution than inverse multiplexing is the direct connection of T-3 UNI at the two ends of West DATS as shown in Figure 7. Using a T-3 UNI allows the users to manage the system based on bandwidth instead of channels.

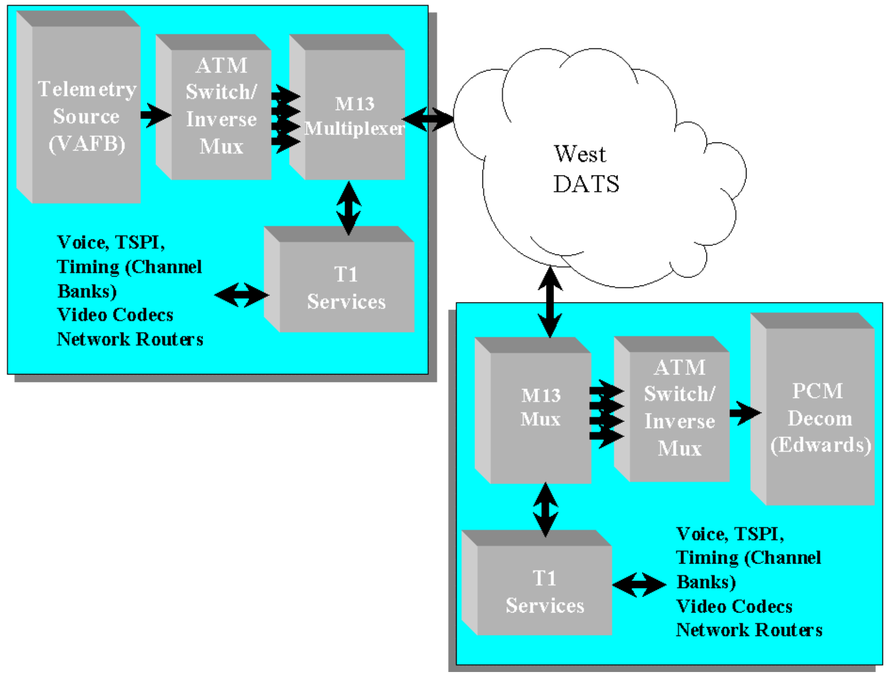

Figure 6 - West DATS Architecture Using Inverse Multiplexing and M13 Multiplexers

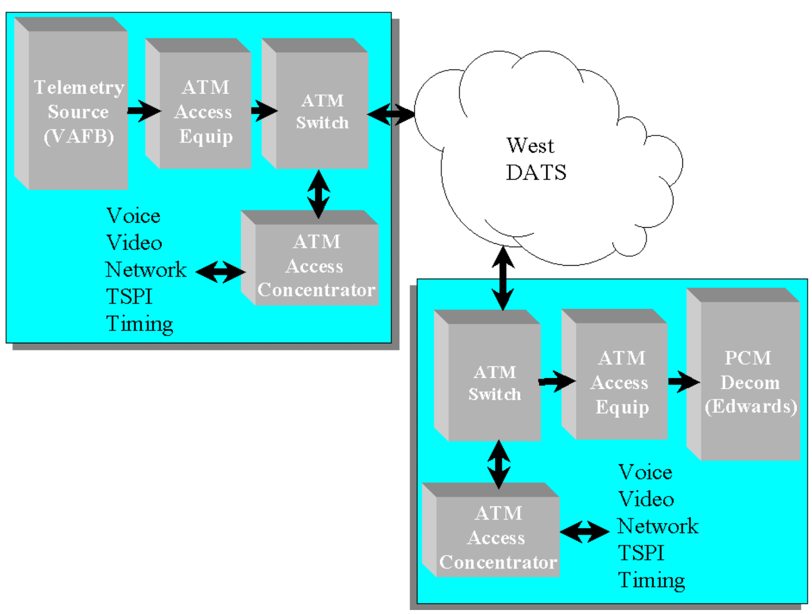

Figure 7 - West DATS Architecture Using ATM Network

Conclusions

ATM has a place in the flight test community, but several problems must still be resolved. The ability to simultaneously transport multiple types of data over a single link and manage the bandwidth instead of channels provides a flexibility that currently does not exist. Using ATM allows the user to trade off quality of service versus number of circuits. For instance, instead of running video at 40 Mbps, the user may tradeoff quality of video, say at 20 Mbps, and add a network connection of 10 Mbps and two telemetry streams near 5 Mbps.

The only known problem for ATM integration into the flight test range environment is the clock reconstruction issue. Several solutions are possible. The ideal solution is for access equipment into an ATM network for telemetry that would perform clock reconstruction. The outputs of this end equipment might be selectable between a T-3 UNI and a T1 inverse multiplexer. Real-time support could be supported today provided the clock stability driving the instrumentation package is stable enough. To ensure this stability, slaving the instrumentation clock source to GPS is recommended. By slaving the clock source to GPS, the manual reconstruction issue may disappear allowing a GPS synchronized clock source to drive the output of the AAC-3 (in the case of this test).

A Small Business Innovative Research topic has been submitted by the Air Force Flight Test Center to investigate ATM access equipment capable of performing clock reconstruction. In addition to clock reconstruction, the end equipment should support multiple data streams, inverse multiplexing, and T-3 UNI interfaces.

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