A NOVEL APPROACH FOR TELEMETRY TRANSMISSION OF COMPUTER DATA

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ABSTRACT

The Telemetry Group of the Range Commanders Council has provided suggested standards for transmission of telemetry data. These standards were necessary to promote compatibility of operational equipment at the respective Test and Evaluation ranges.

For digital transmission, the applicable standards define the frame and word formats necessary for range compatibility. These standards were developed for acquisition of multiple analog and bi-level signals and provided a relatively straight forward means of developing an aggregate, time-division multiplexed (TDM), serial, data stream which includes the information necessary to reconstruct the signals at the ground station prior to analysis. The Inter-Range Instrumentation Group (IRIG) formats are, by design, periodic and form a matrix of “words” which are preassigned to each and every signal being encoded and transmitted. As all the original information is continuous in nature, the encoder must sample each of the channels in their proper sequence and place the sampled data in it’s respecitve time slot.

This paper will address some of the buffering techniques used to transmit data in an integrated IRIG format. We will then address an alternate solution to transmitting computer data for ground based analysis and processing, i.e., transmission of data using commercial type modems.

INTRODUCTION

Computer data offers a unique and sometimes complex challenge when one tries to telemeter such data using IRIG formats. Ideally, one would like to synchronize the encoding process, i.e., the IRIG formating matrix position (time slot). However, computer generated data is generally not repetitive enough to permit such synchronization and precludes simple insertion into an IRIG format. And, when it is repetitive, the speeds involved sometimes make the synchronization task difficult.

Synchronous Data

Synchronous data is usually generated by a computer or processor which is providing for analysis of a sensor that has a periodic motion to it, such as an image scanner. Because of the periodic nature of the sensor and, therefore, its processing algorithm, the data can be generated in a known and periodic format. By providing a synchronization signal to the telemetry encoder, the IRIG format can be generated totally synchronous to the sensor and its data. The data can then be buffered and properly inserted in its assigned time slot.

Asynchronous Data

Asynchronous data can take many forms. It can be generated as a continuous stream of data at a known rate, but related to its own clock rather than that of the IRIG encoder (correctly called isochronous). It can be generated in bursts of data, at a known baud rate and known burst rate, with a fixed number of bits or words in every burst. Or, the burst rate may vary. Or, the number of words (bits) in each burst may vary. Lastly, it may be truly asynchronous, using start/stop data formats similar to the old teletype machines.

SYNCHRONIZING FOR IRIG FORMATS

Single Buffer Synchronization

It is the authors’ belief that single buffer synchronization should only be used in systems where the data is generated synchronous to the encoder. As was mentioned above, such synchronization can be achieved by slaving the encoder to a timing signal which marks a specific time with respect to the data being generated, e.g., the beginning of a scanning event. Alternatively, the encoder could generate a timing signal that would trigger the data generator to send its data at the preset rate. In either case, the data is stored in the encoder for a short period of time so as to allow for the exact timing of word insertion into the frame.

There are circumstances where single buffering must be used for insertion of asynchronous data into an IRIG format. For example, in a system where volume does not allow for additional hardware necessary for other buffering schemes, the single buffer must be employed. In this situation, a dual-port, random access memory (RAM) is used and the buffer (the RAM) is intentionally set higher than the write rate (the rate at which the data is written into the RAM). However, when the read rate is set higher than the write rate, the read function will eventually catch up with the right function and will then start reading “old” data. This event must be flagged to the receiving computer or it may be very confused by the this occurance. One usually tries to insert an “old data” flag so the receiving computer can ignore the information. This “old data” flag is inserted in the RAM the first time the specific word is read for transmission. This flag is usually an extra bit which is set to one polarity when the data is first read into the RAM, and over-written with the opposite polarity when the data is read for transmission the first time. Alternatively, one could write an extra bit as a ONE for one given block of data and a ZERO for the next block of data, continually alternating the polarity of this bit on a block-for-block basis. This technique does not require the over-writing previously mentioned and can, therefore, process data at a faster rate. But, it is more difficult for the ground terminal computer to reassemble the sequence of data originally generated.

Double Buffer Synchronization

Double buffer synchronization utilizes two, full-size equal, RAM buffers, the size being equivalent to one frame of data. While the data generator is writing into one of the buffers, the encoder is reading from the other. Once that second buffer is empty of new data, the encoder switches over to the first buffer and begins reading that data.

As with the single-buffer system, the read rate should be designed to exceed the write rate so data is not lost. Obviously, sooner or later the read function will empty a buffer and not have a full one to which it can be switched. At this point, a decision must be made to re-read the buffer it just completed, allowing the other buffer to fill. When a decision is made to allow a repeated read cycle, a flag must be raised to inform the receiving processor that this information is a repeat of that which was just received. However, this flag need be only one bit per frame rather than one bit per word as was required above. Usually, one decides to use a bit within a word that is not fully utilized, for example the subframe identification or a partially filled bi-level word. For more robust signalling, more than one bit per frame should be used, as a single-bit error impacting that one flag bit could cause us to believe a particular frame is a repeat when in fact it is not, or vice-versa.

Triple Buffer Synchronization

Triple buffer synchronizaiton (Ref. 1) should be used when the data generator is unpredictable. In this situation the full message might appear in bursts with long breaks in between due to the fact that the data generator has been interrupted and is off accomplishing a higher priority task. The three buffers are set up so that one is acting as the source of data for the encoder, one is being loaded by the data generator and the third is standing by waiting to receive the next block of data from the data generator. As with the prior discussions, the read rate must exceed the write rate and a signal flag must be sent to indicate a repeated block of information.

WHY SYNCHRONIZE AT ALL?

The above buffering techniques offer complex solutions to a problem which is becoming more and more common. More sophisticated vehicles and weapons have on-board computers whose data gathering and decision making functions must be monitored and verified during development tests. Also, the more one uses the computer to achieve on-board processing, the less time will be available for the computer to be concerned with providing telemetry data in a format compatible with a telemetry system encoder. Although the above solutions achieve the desired goal, the expense related to initial design engineering plus the cost of assembling and testing the production systems might be offset by an alternate solution, a separate transmission link for the computer data.

From a cost trade-off viewpoint, one must consider the cost of the added hardware required to interface the computer with the transmitter, the cost of the transmitter, and the cost of ground station equipment to reconstruct the data for communicating with the ground station computer, assuming the on-board computer does not have the luxury of being able to generate the data in an IRIG compatible format.

In other words, what technique or techniques can be used to enable two computers to communicate in a simplex mode via a radio frequency (RF) link? The solution is a digital-input transmitter with a receiver/bit synchronizer combination at the receive station. However , for low bit rates, a simpler solution became obvious. The answer is modems.

MODEMS

The word “modem” is an acronym for modulator-demodulator. It is a device which converts one form of signal to a second form which is more compatible with the media to be used for communicating the information. In today’s world of personal computers, computer time-share terminals and computer-to-computer communications, the modem has become a widely used device for providing a means of digital communications via telephone systems. Most digital communication is achieved with devices called wireline modems. But, there are also a significant number of limited distance modems available for digital communications via a limited length of a pair of wires.

Wireline Modems

Wireline modems, as the name implies, are designed to communicate over hard wire systems. Specifically, they are designed to operate within the telephone system hierarchy of voice channels. The rates of these devices run in the 75 times 2^n family of baud rates, that is, 300, 600, 1200, 2400, 4800, and 9600 baud. Manufacturers have developed the high rate modems using multiple modulation schemes, generally combinations of amplitude and phase modulation. Interestingly, they have been successful at packing the 9600 baud channel into under 3 Kilohertz of audio bandwidth.

These devices are rather expensive and need a communications channel with a signal-to-noise ratio in excess of 25 dB to provide error free communications. We will see in the following discussion that although the wireline modem is an interesting communicating tool, there is a less complex device to be considered.

Limited Distance Modems

The limited distance modem (LDM) was developed to replace the wireline modem when the communications channel was of better quality than the standard voice grade line. This is typically found in intra-facility computer systems where communications is to be maintained over a distance of a few thousand feet, and the media is a simple, dedicated, twisted pair of wires. Some units are capable of data rates up to 19,200 baud and can be operated at any rate to that maximum, even non-standard rates.

It was these simple characteristics that intriqued us, and enabled us to consider the use of such simple devices for airborne digital commmunications.

Although the LDM is designed for operation over wire, we figured it should be just a capable of operating over a radio link which had characteristics comparable to that of a hard wire pair. We had to determine the bandwidth requirements and signal-to-noise requirements for error free communications. For the purpose of our investigation and for the application at hand, we chose to look at one particular unit. The unit we chose is manufactured by Gandolf Data, Incorporated of Wheeling, IL.

The Gandolf Model mLDS 122 modem, called an asynchronous mini local data set, is a small, inexpensive, commercial device designed to operate at rates to 9600 baud. It provides for limited, RS-232, digital, interface signalling and is transformer coupled to the communications link on both the send and receive side. These units are designed for full duplex operation although we were only considering it for simplex operation.

Initial investigation resulted in the realization that the LDM is better suited for the standard telemetry transmitters and receivers than was originally thought. First, this particular LDM does not require dc coupling. Second, the baseband bandwidth of the modulated signal was approximately 20 kilohertz. Typical S-band and L-band transmitters and receivers prefer to be ac coupled, thus removing the effect of carrier shift. Also, intermediate frequency (IF) bandwidths in these receivers are maintained at 200 kilohertz or larger. Baseband bandwidth is usually designed to be 0.25 times the IF bandwidth, or no less than 50 kilohertz.

In utilizing the LDM, we had one concern. How would the LDM react during fades in the RF link? It quickly became obvious there was no protection against such problems. After all, how often does one observe a fade in copper wire?

We solved that problem by inserting a limited bandwidth noise detector in the receive terminal. This noise detector monitored the output of the receiver and when the noise level in the 45 to 50 kilohertz band exceeded a predetermined threshold, we forced the RS-232 signal Data Carrier Detect (DCD) signal to indicate a loss of carrier on the link, informing the receiving computer that the data now being received is garbled and should be discarded.

The modified modem is depicted in Figure 1. The receiver output signal is applied to the 600 ohm transformer input of the LDM and, in parallel, to a high-impedance isolation amplifier. The output of the amplifier is filtered by the bandpass filter, the characteristics of which were nominally 47.5 KHz center frequency, bandwidth of 5 KHz, and a roll-off of 12 dB per octave. The filter output was applied to peak detector, with the output being applied to a threshold detector. This threshold detector generated the above mentioned DCD signal.

TYPICAL APPLICATIONS

Figure 2 shows block diagrams of two, simplex, digital data links. The upper block diagram, Figure 2a represents a typical link for synchronous transmission of data. In this implementation, the computer drives a digital transmitter (dc coupled with integral pre-modulation filtering). At the receive terminal, we have a standard receiver followed by a bit synchronizer. The bit synchronizer, in turn, drives the computer. Note, there is a limitation in that the computer must provide a significant amount of data transitions to maintain the bit synchronization. Alternatively, the computer could transmit in a bi-phase format, but this doubles the bandwidth of the transmitted signal.

Figure 2b represents a data link using the LDM philosophy. In this application, the computer provides an RS-232 data signal to the LDM along with a Data Terminal Ready (DTR) and a Request to Send (RTS). The latter signals are necessary as they are actually the source of power for the LDM. The LDM transmits its “analog” output signal via a standard transmitter. The receiver regenerates the “analog” signal and applies it to the LDM for subsequent regeneration of the RS-232 data signal. At the receiver terminal, the LDM must receive its power from the same signal lines, i.e., DTR and RTS. If such signals are not available, they must obviously be simulated by tying them to a dc source of between six and 12 volts.

The advantage of this latter implementation if twofold. The computer need not concern itself with data activity to maintain bit synchronization, and any data rate to 9600 baud can be transmitted without presetting any of the equipment. (We mention a limitation of 9600 baud. This limitation is only due to the specific device we selected. Subsequent search of the industry has indicated that similar devices are available with operating baud rates up to 56 Kbaud per second).

The above discusses simplex links. With little addition of hardware, a duplex link can be achieved. Reference Figure 3. This implementation is representative of that which one might find in an RPV or unmanned vehicle application. By the addition of the additional transmitter and receiver, and the two diplexers, the two computers can converse in a full-duplex mode., i.e., both directions at the same time. The rates and activity in both directions are independent of each other.

LINK PERFORMANCE

We were confident enough in this LDM concept that we proposed the use of a system, similar to that of figure 2b, for simplex transmission of data from an unmanned vehicle to a ground station. The vehicle contained several sensors used to gather data up to 300 nautical miles from the ground station. The planned mission for the vehicle was to fly to a remote area, gather data, process the data and then climb to an altitude which would permit line-of-sight transmission to the ground station

The vehicle’s on-board computer was designed to provide data for transmission for intervals of 30 to 45 seconds after 15 to 20 minutes of data gathering. Because of this burst mode of operation, and the low duty cycle required, a transmitter power switch was implemented which responded to the Request to Send (RTS) signal generated by the computer’s RS-232 interface. Properly programmed, the computer was then able to power up the transmitter a few hundred milliseconds prior to data transmission.

The transmitted power was to be 40 watts, minimum. To achieve this we used a 2 watt transmitter followed by a 40 watt, Class C, power amplifier. the intermittent carrier from the transmitter allowed the power amplifier to cool during the off cycle, thus, requiring a minimum of forced air and conduction cooling of these units.

The receive unit was required to be on 100 percent of the time, awaiting the data transmission. During the off time, the receiver is at maximum sensitivity, and the FM detector generates random noise. By measuring the out-of-band noise we were able to detect the absence of transmission. Once a proper carrier was received, the noise detector released the Data Carrier Detect (DCD) line and the ground computer started to read the data provided to it through the RS-232 data port.

The design requirements for the system were:

Range	300 NM
Altitude	10,000 feet
Link Frequency	L Band (1.5 GHz, nomimal)
Antenna, Airborne	Omni-directional
Antennae, Ground	Omni-direcitonal and Directional Helical (switchable)

A quick link analysis indicates the following expected performance.

Transmitter power	46.0 dBm
Cable loss, Transmit Terminal	-1.0 dB
Transmit Antenna Gain	0.0 dB
Path Loss	-151.0 dB
Receive Antenna Gain (Helical)	12.0 dB
Cable Loss, Receive Terminal	-1.0 dB
Receive Carrier Level	-95.0 dBm

Noise (200 KHz IF BW)	-121.0 dB
Receiver Noise Figure	4.0 dB
Noise at FM Detector	-117.0 dBm
Carrier-to-Noise Ratio	22.0 dB
FM Threshold	-12.0 dB
Link Margin	10.0 dB

The transmitter characteristics were selected so as to guarantee a high quality signal at the receive LDM, even as we approach FM threshold. At FM threshold, i.e., 12 dB above the noise level of -117 dBm, we anticipated link degradation.

MEASURED PERFORMANCE

The system described above was tested in the laboratory by replacing the antennae with coaxial cables, directional couplers and suitable attenuators to provide a calibrated input to the receiver. Messages were transmitted from a laboratory computer through the “data link” via its RS-232 port. The single computer port was used for both send and receive signals. The link was also tested with a data an analyzer, using its pseudo-random pattern generator to establish quantitative bit-error performance. The bit error measurements are tabulated below.

RECEIVER INPUT (dBm)	BIT ERROR RATE (TIMES 10^{-6})
-102	0
-103	0
-104	0
-105	4
-106	138
-107	742
-108	3252
-109	12392

The system ran error free at -104 dBm carrier level. Thus, the above asumptions and calculations were verified.

As a post script, the customer has flight tested the above described system and has stated the link performed flawlessly during all phases of the flight test program. A photograph of this data link is included as Figure 4.

CONCLUSIONS

The most important conclusion that can be presented is the fact that modems, and specifically LDMs, can be used to interface computers with RF data links. But, just as important, maybe its time we stepped back and looked at the requirement for telemetry transmission of computer data. is a ruggedized LDM the solution to asynchronous, computer data transfer for telemetry and communication applications in the future?

Reference

1. Giije, Harold B. and Nicolas, Raymond F; Techniques for Acquiring Digital Data from Intelligent Subsystems", Proceedings of the International Telemetry Conference, 1983, pp 433-440.

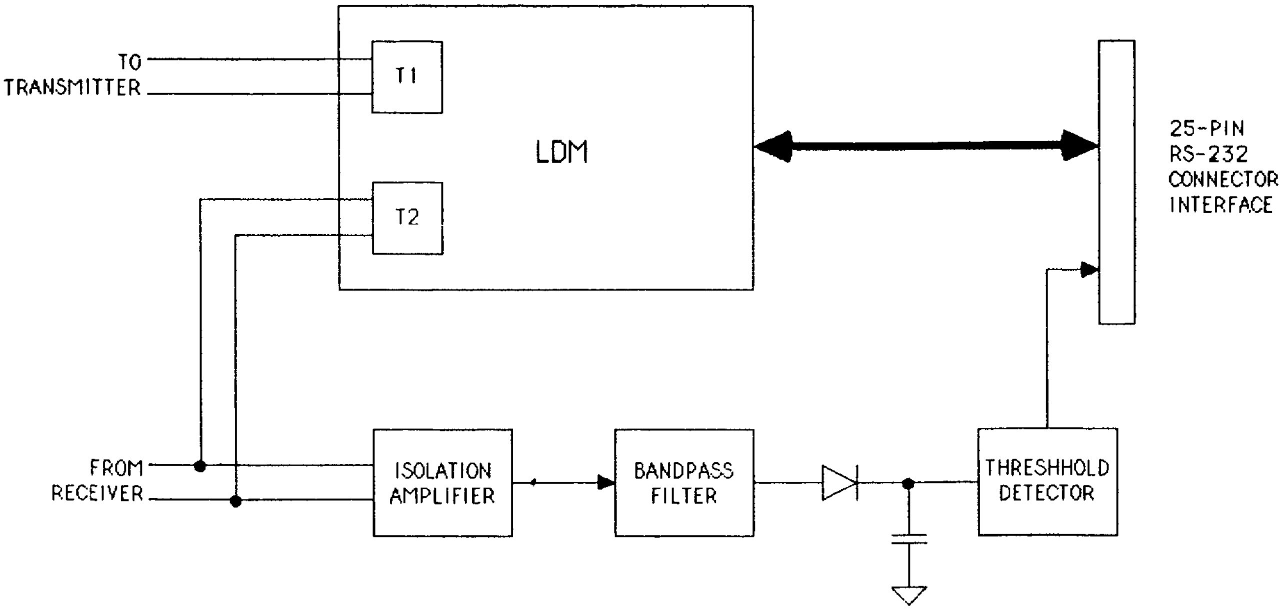

Figure 1, Full Duplex RS-232 Modem

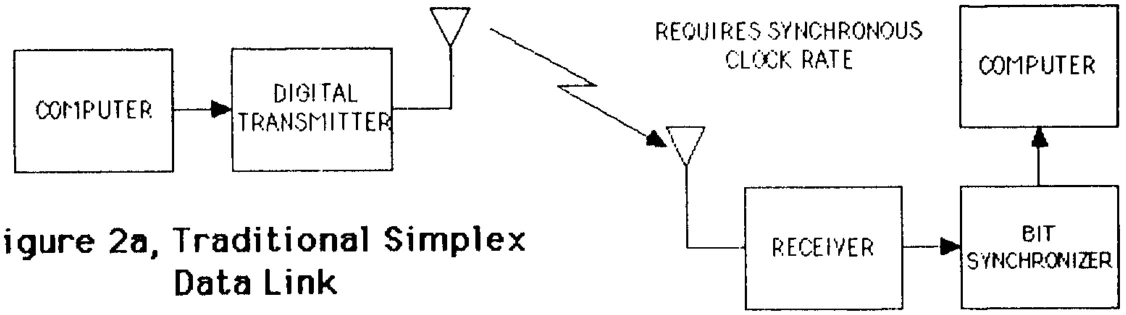

Figure 2a, Traditional Simplex Data Link

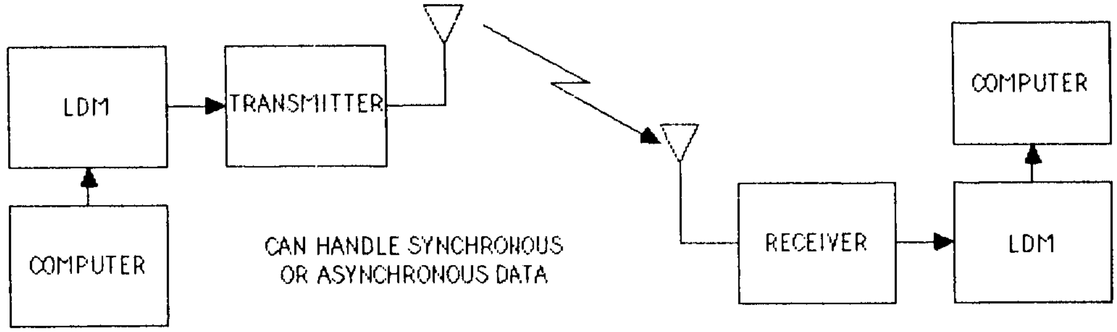

Figure 2b, A Simplex Data Link Using LDMs

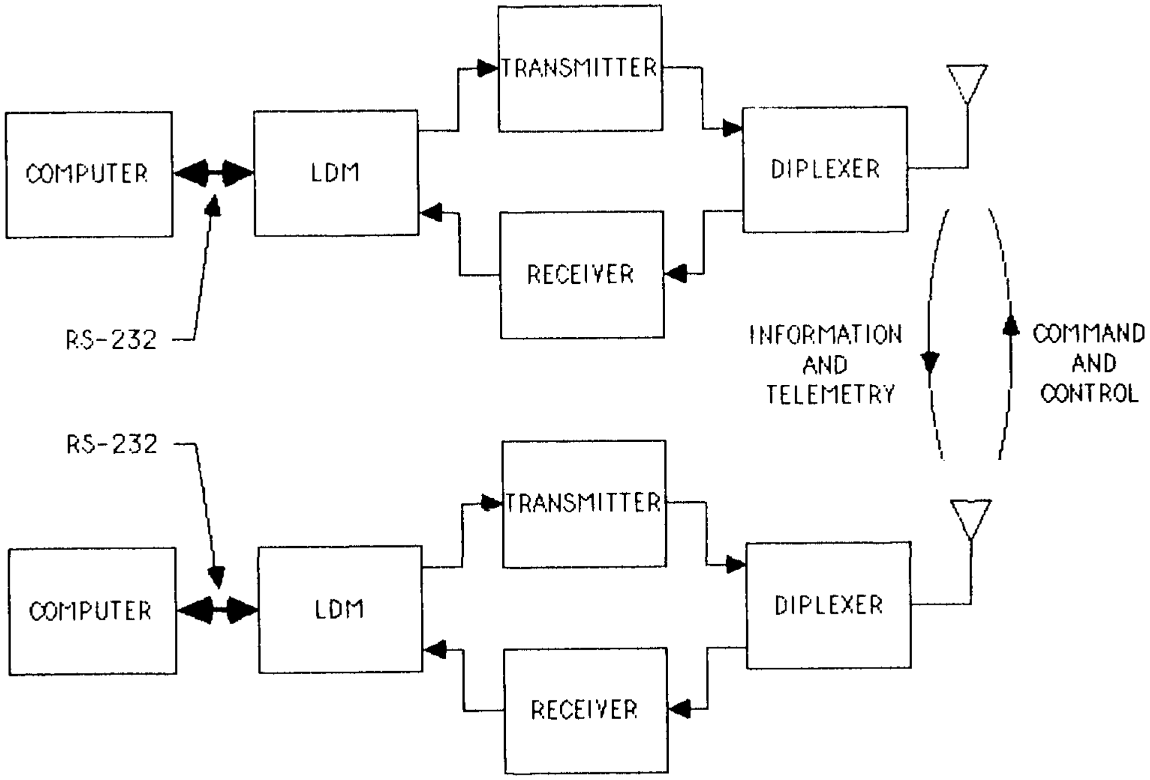

Figure 3, A Full Duplex Data Link Using LDMs

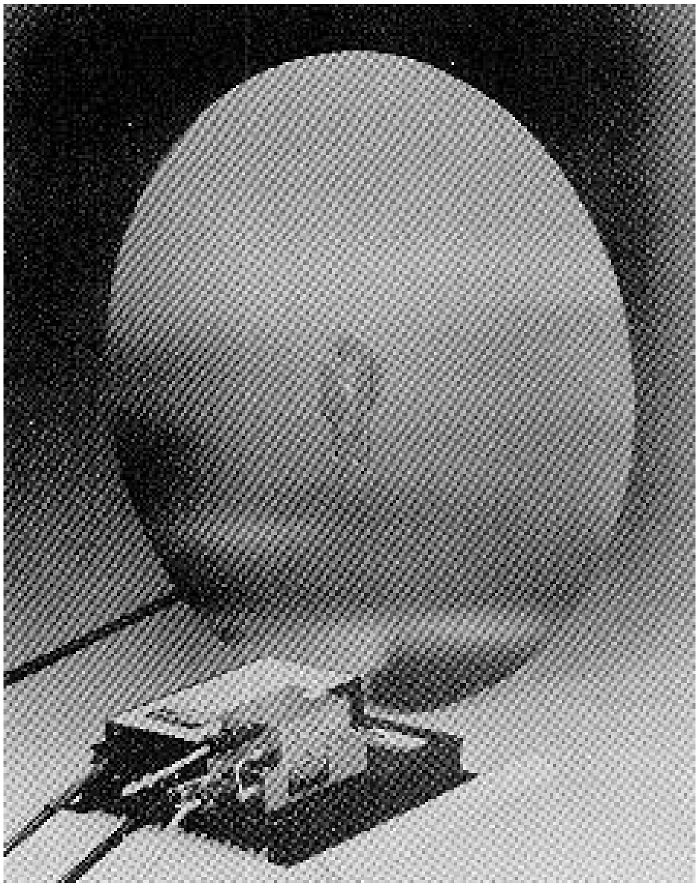

Figure 4, The Simplex LDM
Data Link