MINI MODEM FOR PTTI DISSEMINATION

by

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Precise comparisons of clocks are now regularly made over several Defense Satellite Communication System (DSCS) trunks employing communications modems that use high-speed pseudo-random codes. Under the primary sponsorship of the Naval Electronic Systems Command, the Naval Research Laboratory (NRL) is continuing the development program to extend the use of the technique to certain other stations that are not equipped with appropriate modems. The Army has also contributed to the development funding and will be furnished with a time transfer system between two of its satellite terminals.

While the development effort is directed mainly at satellite time transfers, the techniques and equipment may also be used in other communications systems, such as line-of-sight microwave links. The techniques are intended to make use of existing communication facilities in a non-interferring manner wherever possible.

Time comparisons were made over DSCS trunks using existing AN/URC-55 communications modems by monitoring certain points on their high-speed pseudo-random codes. The ability to recognize such a point on both ends of the circuit is equivalent to transmission of a very short pulse over the circuit. To make clock comparisons, the signals that are transmitted in both directions between the terminals are monitored by devices called time transfer units, which are inserted between the URC-55 modems and the clocks at both stations as in Figure 1. Accuracies in the order of 0.1 microsecond have been realized in long distance comparisons using this equipment, and several stations are served by the Naval Observatory time standard through single or multiple-hop satellite time comparisons.

The time transfer technique requires each station to transmit a pulse and to receive the pulse transmitted by the other station. At each terminal, the transmitted and received pulses are compared with the local clock. If half the sum of the two measurements taken at one station is subtracted from half the sum of the measurements made at the other station, the difference is the actual difference between the two station clocks (see Figure 2).

This relationship is valid if the propagation time $\tau_1 + \tau_2$ in one direction is equal to the propagation time in the reverse direction. When using the slow-moving DSCS satellites, the inaccuracy is less than 0.1 microsecond if the two transmitted pulses occur within approximately one second of each other. It is not necessary to control the timing of the transmitted pulses, in that case, except to have them occur at roughly the same time. An interpolation technique has been worked out for use when the transmissions cannot be approximately synchronized.

Figure 3 shows the CM-427 time transfer unit developed at NRL last year which automatically compares the transmitted and received pulses at each station with the local clock and yields a burst of pulses that is equal to half the sum of the two time intervals. This burst is totalized in an electronic counter that is used merely as an accumulator. The time difference between the clocks at the two stations, then, is simply the difference between counter readings at the two sites.

For time transfers between stations that are not equipped with the URC-55 modems, an experimental modem designed specifically for time transfer service was developed last year and was used successfully to make satellite time transfers. That model, intended only to demonstrate feasibility, has been redesigned, and the second version is near completion.

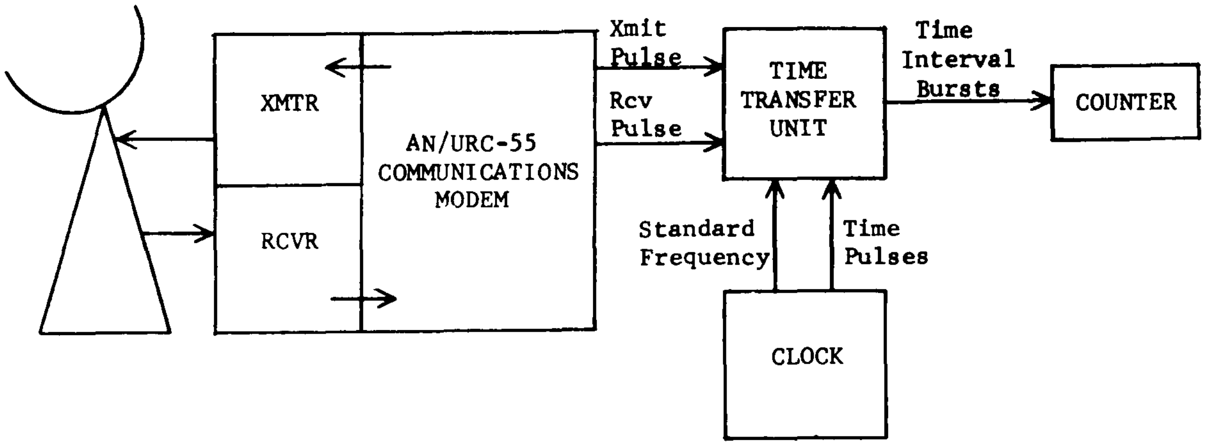


Figure 1. CONFIGURATION FOR TIME TRANSFER WITH AN/URC-55 MODEMS

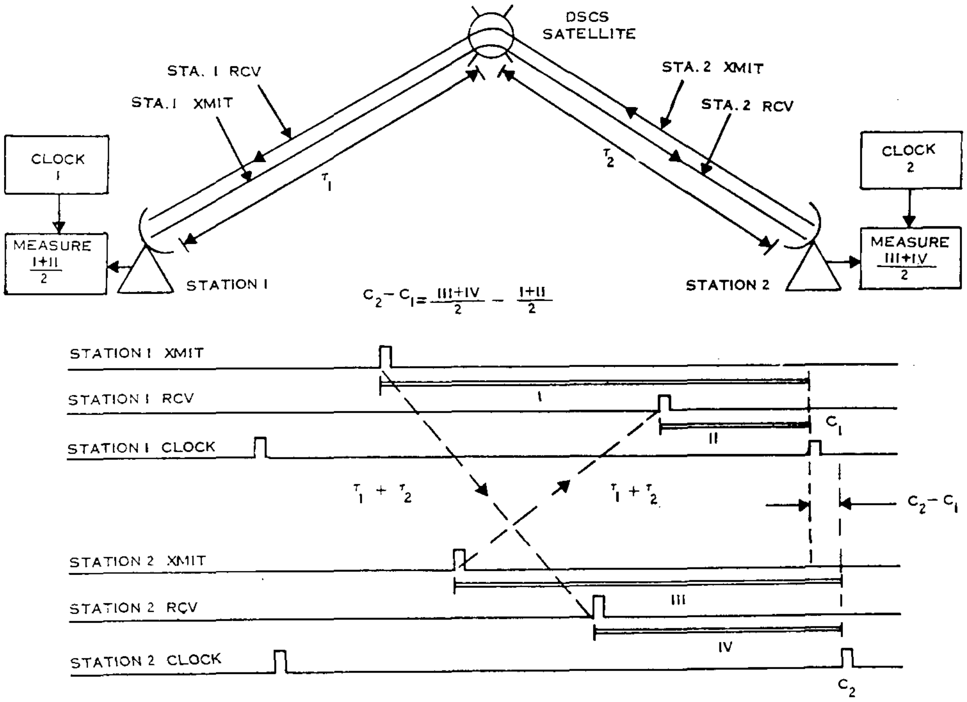


Figure 2. TIME TRANSFER TIMING DIAGRAM

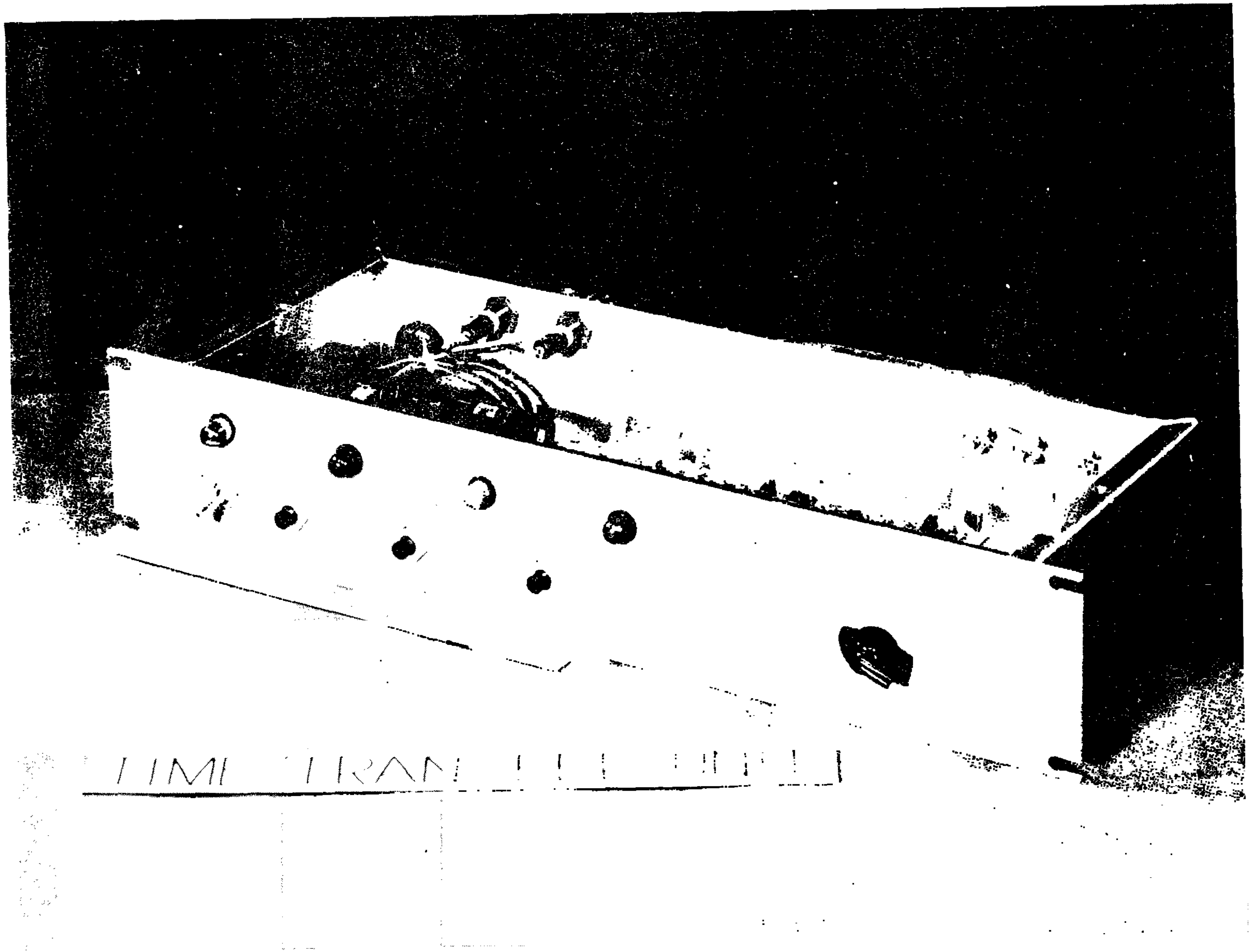


Figure 3. TIME TRANSFER UNIT

The improved model, shown in Figure 4, employs the same basic principles that were used in the original version. The improvements include the increased use of synthesized frequencies based on the local clock in place of crystal-controlled oscillators and increases in operating tolerances.

The design of the newer equipment has been made with a view toward the possible use of the modem over line-of-sight microwave links as well as in satellite systems. Two modes of interfacing are to be available. One is a 70-megahertz intermediate frequency connection. The other is a baseband interface for use in systems through which there is no frequency translation.

The modem transmitter at the bottom of Figure 5 normally provides a 70-megahertz output that is bi-phase modulated by the code generator. The code-rate oscillator function in the new modem is a synthesized frequency controlled by the accurate local clock.

Once during each cycle of the 8,191-bit code, an "all-ones" pulse corresponding to the "all-ones" state of the shift-register code generator is gated out. Several code rates will be available between 1.25 megahertz and 10 megahertz. At 10 megahertz, the code cycle is 819 microseconds long, and at 1.25 megahertz, the code cycle length is 6.5 milliseconds.

On command of an initiating pulse, the "polarity inversion sequence and all-ones gate" causes the code polarity to be inverted for one complete code cycle beginning at the next all-ones event. At the end of the cycle, an all-ones pulse designated as the "tranmit time tick" is gated out. The code then returns to its original polarity.

The receiver section of the modem in the upper part of Figure 5 contains a shift-register generator that produces a code identical to the one generated by the transmitter of the other station. The rate of the receiver code generator, however, is controlled by a variable rate frequency synthesizer that is automatically adjusted to acquire accurate alignment with the code modulation of the received signal.

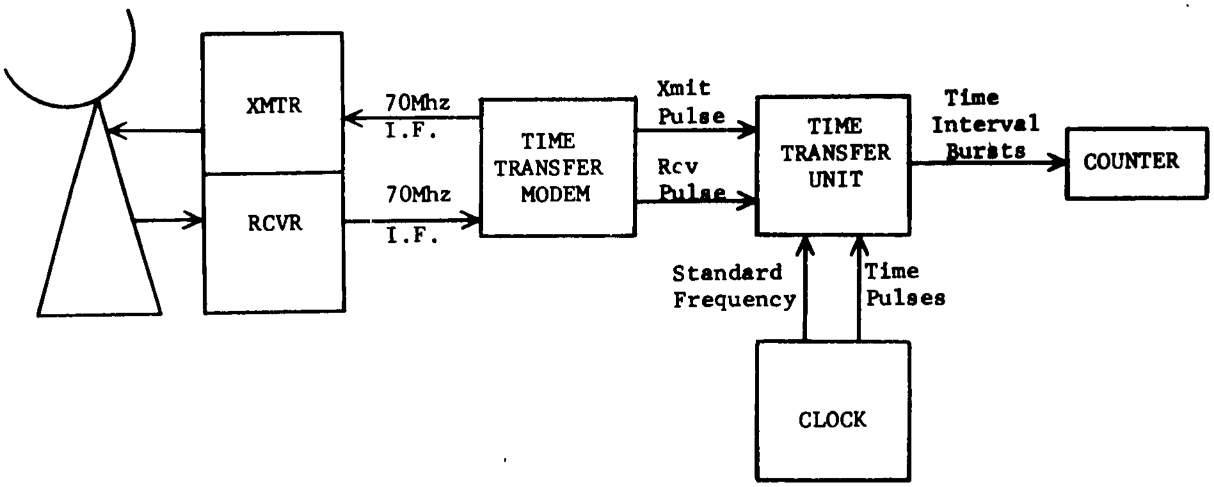


Figure 4. CONFIGURATION FOR TIME TRANSFER WITH TIME TRANSFER MODEMS

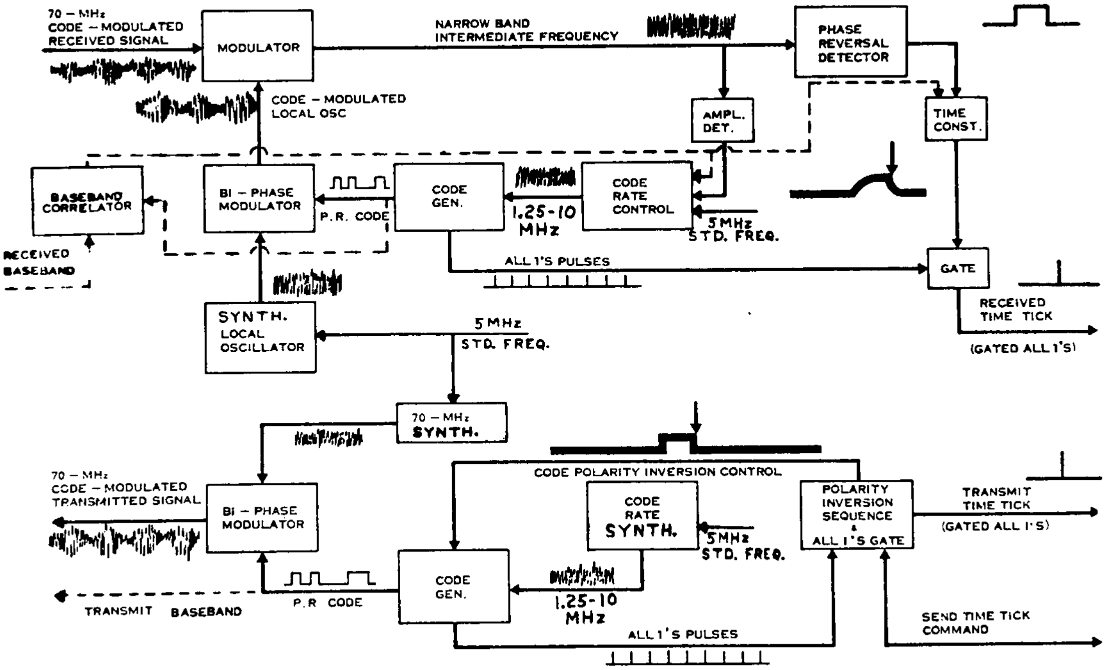


Figure 5. TIME TRANSFER MODEM TRANSMITTER AND RECEIVER

When alignment is achieved, the output of the bi-phase modulator is a nearly constant-phase (or narrow-band) intermediate frequency. The amplitude of this intermediate frequency decreases essentially to zero as code misalignment is increased to one bit (0.1 microsecond at 10-megahertz rate), and it is possible to maintain alignment to within a small fraction of a bit by maintaining peak amplitude. The code rate control, therefore, is designed to maintain peak output of the amplitude detector. Matching the codes is a narrow-band process that can be accomplished in the presence of large amounts of uncorrelated noise, and the modem may be operated at a level considerably below other signals occupying the same channels.

A phase-reversal detector, consisting of a phase-locked oscillator with a large time-constant loop, senses the reversed code cycle and gates out the succeeding all-ones pulse, which is the designated receive time tick.

Connections for baseband operation are shown by dotted lines in Figure 5. This arrangement bypasses all of the 70-megahertz circuits in both transmitter and receiver. The filtered output of the baseband correlator, which reaches a peak output when the receiver code generator is aligned with the received signal, is applied to the code rate control. Detection of the inverted code cycle is simply a matter of sensing an amplitude or polarity change in the correlator output.

Considerable simplification of the modem would result if its operation were restricted to the baseband mode. This might be done if the tests show the mode to be sufficiently useful.

As shown in Figure 6, one code is used for transmission in one direction, while a different code is used in the other direction. The receiver of one modem, therefore, ignores its own transmitter, even when the transmit and receive signals occupy a common channel.

In an experiment in which signals were sent simultaneously in both directions through a single coaxial line, it was possible to operate with a 20-db difference between transmitter outputs. This required, of course,

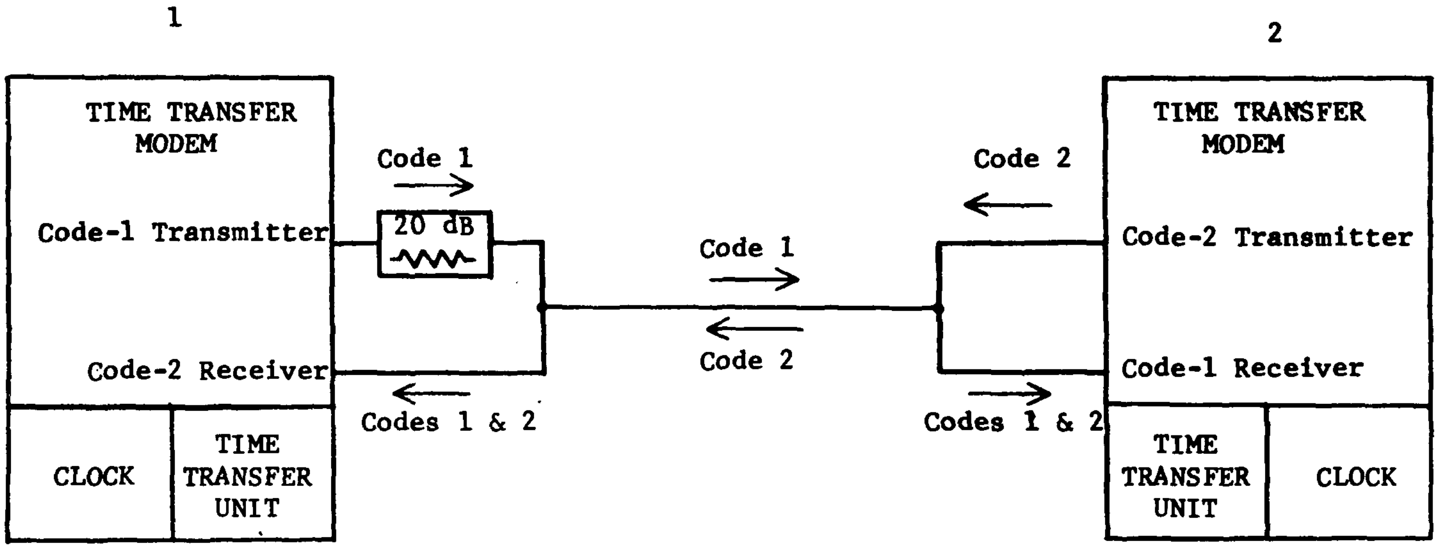


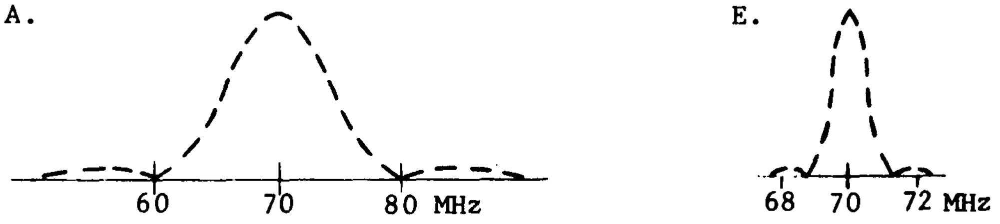
Figure 6. DUPLEX OPERATION OVER SINGLE COAXIAL LINE

that the transmissions in one direction operate 20 db below the pseudorandom interference generated by the other transmissions. Operation in the presence of continuous wave (CW) interference of the same order of magnitude has also been achieved in laboratory tests.

The total bandwidth of the modem 70-megahertz IF output is approximately 20 megahertz, as shown in Figure 7-A when used at its maximum, 10 megabit-per-second code rate. By selection of other rates, the IF bandwidth of the new modem may be reduced to as little as 2.5 megahertz as drawn in Figure 7-E. While potential resolution is reduced at the lower bandwidth, it is felt that the accuracy, exclusive of differential delays in the transmission medium, will remain in the range of one or two tenths of a microsecond, because the code matching in the modem receiver is maintained to within a fraction of a code bit.

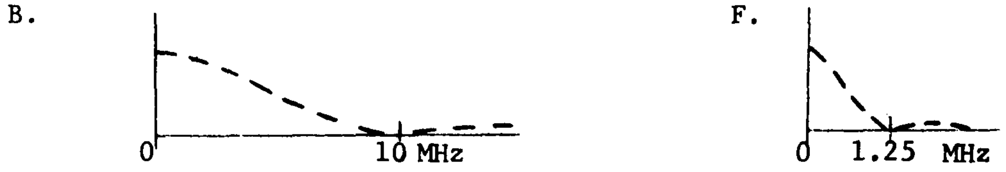
The original time transfer modem produced only the spectrum of Figure 7-A. On certain satellite circuits, it shared the channel with a few relatively narrow-band communications circuits as shown in Figure 7-C. Since the spectrum of this modem is spread out over a large frequency range, the amount of power appearing in any of the narrow-band channels is quite small. A further reduction in interference to the communications channels is available because of the ability of the modem to operate significantly below their power level. This ability is of value particularly where the peak power of the transmission system is (or must be) limited.

The baseband output of the modem will appear as the spectra of Figure 7-B or 7-F. Two intermediate code bit rates of 5 and 2.5 Mbps will provide other bandwidths between those of Figures 7-B and 7-F. These spectra are simply those of the transmitter code generator. The signal would not be applied to systems in which the baseband is subjected to frequency translation, even though the baseband is later recovered, because phase uncertainty in the recovery could impair reception of the signal. The baseband signal might be used, however, with systems in which the baseband



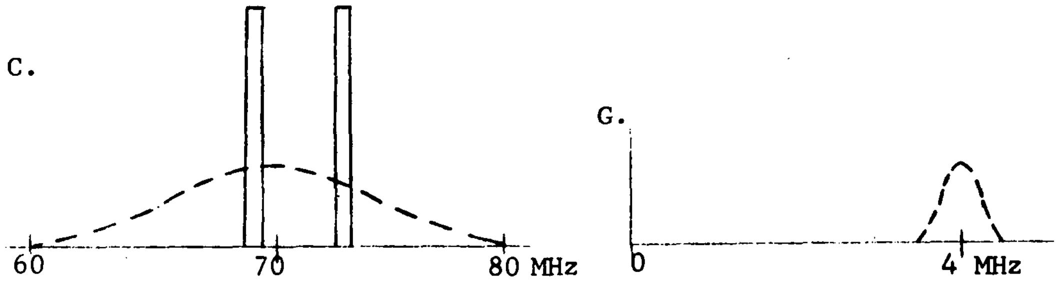
10 Mbps Spectrum (70 MHz I.F.)

1.25 Mbps Spectrum (70 MHz I.F.)



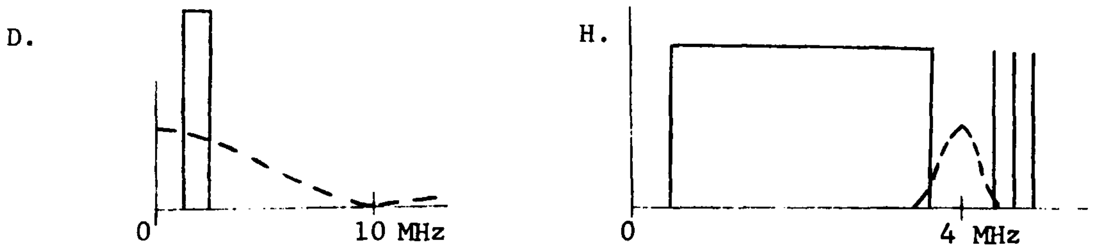
10 Mbps Baseband Spectrum

1.25 Mbps Baseband Spectrum



10 Mbps I.F. Sharing Channel with Narrow-band Signals

1.25 Mbps I.F. Converted to 4 MHz



10 Mbps Baseband used on Underutilized Communication Channel

Converted 1.25 Mbps used in Vacant Channel Space

Figure 7. MODEM SPECTRA

directly modulates the amplitude or frequency of a carrier,and recovery of the baseband is accomplished at the receiver by a simple amplitude detector or frequency discriminator.

In systems such as those of Figures 7-C and 7-D, in which only a small portion of the channel is used for communications purposes, the density of the modem spectrum may be kept low and interference to the communications circuit may be minimized. However, as more communications channels are added within the range of the modem spectrum, the level of the wideband modem signal would have to be increased to maintain operation of the time-transfer system. This increase in signal strength would result in greater interference to each communications channel.

Vacancies or lightly occupied portions of a reasonably full channel might be used for time transfer by converting an IF spectrum of appropriate width to the region of the vacancy. The IF spectrum shown in Figure 7-E for example, might be translated by a simple converter to an appropriate spot such as the one shown in Figure 7-G and added to the communications system baseband as indicated in Figure 7-H at the lower right. The tolerances of the various communications components to the noise density produced by various parts of the time-transfer spectrum would govern its placement.

A local microwave link maintained by the Naval Electronics System Command will be used as a test bed for evaluation of the time transfer modem. Factors of interest include susceptibility of multiplexed voice channels, pilot tones, and control signals to the spread-spectrum time transfer signal and, conversely, the susceptibility of the time-transfer modem to the communications content of the link.

Figure 8 is a picture of the original modem. The time transfer modem was intended primarily for DSCS or other slow-moving satellites, but its tolerances may permit its use in other communications systems. The code generator feedback loop of the receiver, for example, is designed to acquire and

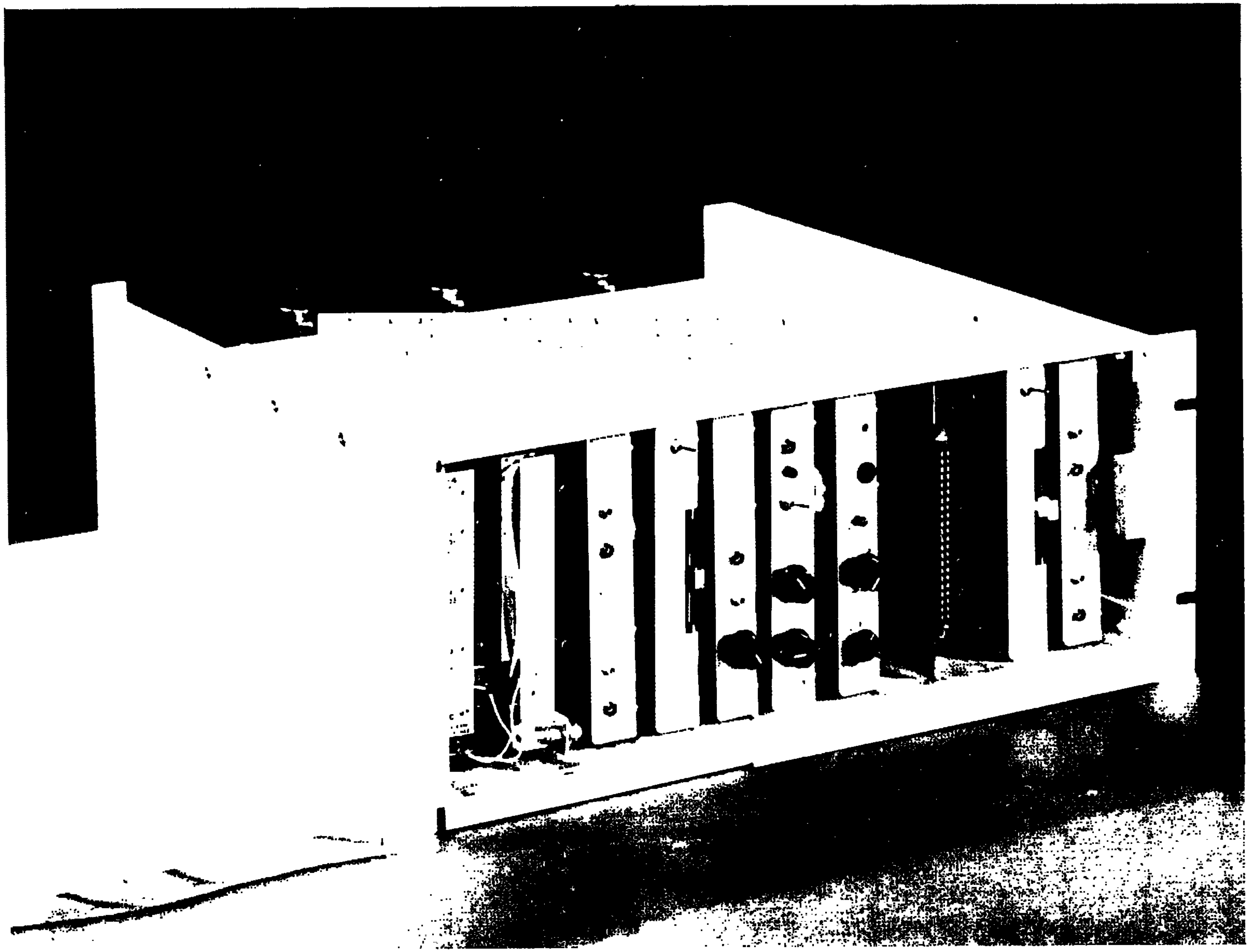


Figure 8. TIME TRANSFER MODEM

maintain lock on signals with Doppler shifts corresponding to a relative motion between stations as large as 1300 miles per hour.

The receiver can operate with offsets of the 70-megahertz input as large as ±10 kilohertz. This tolerance is shared by Doppler shifts which are proportional to the transmission frequency and by frequency translation errors. A Doppler shift corresponding to a motion of over 600 miles per hour using X-band transmissions could be accommodated, for example, if there were no translation error. Defense Communication Satellite equipment and operating conditions fall well within these tolerances.

The new modem, which is 1-3/4 inches taller than its predecessor, will occupy a standard 19-inch panel space 8-3/4 inches high. The increased height permits continued use of some of the original printed circuit cards while providing an operating panel without requiring access to the cards for normal operating procedures.

Planned tests of the modem over satellite systems and a preliminary evaluation over the microwave test system will be completed in the next couple of months. Further evaluation of the modem in conjunction with other developmental PTTI elements may then be made in a proposed precise time and time interval test bed at the Naval Communication Station in Hawaii.

DISCUSSION

DR. WINKLER: This is a strategic planning conference, and there are several items which we ought to know and consider in our planning for further developments. First, there is one point which I found necessary to keep in mind in considering the uses of wideband channels for time transfer; that is, the bandwidth which is used determines the precision of time transfer, or resolution of time transfer. For resolution in the order of tenths of nanoseconds, one does need a bandwidth of tenths of megaseconds. On the other hand, the available or the used signal-to-noise determines the time which one needs to make a time transfer. Conceivably, by making the pseudo-noise code sufficiently long, one could make a time transfer using 10 to 30 seconds or one minute and operate 40-50 db below the level of other signals in the same channel. That is the principle which is really used here. When NRL originally proposed such a mini-modem development, everybody who participated in these discussions considered development of a unit which could be put into those satellite ground terminals which had no modems in order to use them for time transfer. In any such link you need a modem in both of the ground terminals involved, so we have to standardize. Fortunately, thanks to the Army Strategic Command, we are putting some modems into terminals, for example, at Camp Roberts. Camp Roberts' modem will also make that station available for time transfers to additional stations and those will need only one mini-modem. As the development went along, as Mr. Murray has explained, it became evident that that modem will find much wider use than originally planned and I would like to encourage everyone who can see a possible application in his system to please let us know about that. If we go into a production of five modems, it would be extremely useful to know that maybe five or ten more are needed.

MR. MURRAY: With UHF, I think that there are some conceivable problems. Multipath effects could conceivably cause a false lock in a system of this sort. It's probably best used where the signal is relatively concentrated by directional antennas, but I don't think that we should rule this out, since there may be ways around it. We haven't investigated that particularly yet. Other means can be used requiring a possibly longer synchronizing procedure which might be used on UHF.