TIMING AND FREQUENCY CONSIDERATIONS IN THE WORLDWIDE TESTING OF A SPREAD SPECTRUM COMMUNICATION SYSTEM

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ABSTRACT

During 1978 and 1979, an Air Force C-135 test aircraft was flown to various locations in the North and South Atlantic and Pacific Oceans for satellite communications experiments by AFAL. A part of the equipment to be tested on the aircraft was the SEACOM spread spectrum modem developed for NRL by Raytheon.

Test results achieved in the program will be presented. The SEACOM modem operated at X band frequency from the aircraft via the DSCS II satellite to a ground station located at NRL. This modem incorporated the concepts of wide bandwidths, autonomous operation, high frequency multiplication factor and design-to-cost. For data to be phased successfully, it was necessary to maintain independent time and frequency accuracy over relatively long periods of time (up to two weeks) on the aircraft and at NRL.

To achieve this goal, two Efratom atomic frequency standards were used. One of these has been in service at NRL since 1973. One standard was used as a portable clock and the other was used as the modem frequency standard.

This paper will discuss the performance of these frequency standards as used in the spread spectrum modem, including the effects of high relative velocity, synchronization and the effects of the frequency standards on data performance. The aircraft environment, which includes extremes of temperature, as well as long periods of shutdown followed by rapid warmup requirements, will also be discussed. The limitations of maintained time in remote locations such as Thule, Greenland, Ascension Island, Lima, Peru, Hawaii and Dayton, Ohio will also be addressed.

INTRODUCTION

The Naval Research Laboratory and the Air Force Avionics Laboratory are engaged in various programs to improve long range military communications via satellite.

A joint test program was undertaken in 1978 to evaluate the performance of the SHF/EHF Advanced Communications (SEACOM) modem developed by Raytheon for NRL. This project was made part of an on-going comprehensive Air Force program for developing and testing advanced communications systems for airborne applications.

TEST PROGRAM DESCRIPTION

The SEACOM modem is a frequency hopped, spread spectrum system capable of data rates of either 75 or 2400 bps. The system provides half duplex operation at either SHF or EHF with an additional output at an IF frequency of 700 MHz. A detailed description of these equipments can be found in reference 1. The modem was integrated with an Air Force experimental dual band SATCOM terminal (AN/ASC-28) [2] aboard a C-135. Figure 1 shows the test configuration. Two additional modems, at NRL's field site in Waldorf, Maryland, were integrated with either of the two amplifier/antenna configurations shown. The satellite used was one of the Defense Satellite Communications Systems Phase II Satellites [3] which was in synchronous orbit over the Atlantic Ocean.

One of the major objectives of this test program was to maintain and acquire time to an accuracy sufficient for two remote terminals to synchronize the spread spectrum waveform. The purpose of the joint test was to determine the performance of the SEACOM modem under various propagation and flight conditions.

A series of tests were run at NRL's Waldorf field site via the DSCS II satellite; first back to NRL to establish the baseline performance characteristics and then to the aircraft on the ground and in the air in a variety of high dynamic, multipath and elevation angle tests. These tests were conducted with a military aircraft operating out of various U. S. Air Force bases and foreign commercial airports. This paper will describe the techniques that were tried, their relative effectiveness and will also offer some suggestions for future testing.

MODEM TIMING CONSIDERATIONS

The signalling structure of the modem is shown in Figure 2. All timing and data is divided into 4 second frames. Once every 4 seconds during a transmission a 409 millisecond synchronization preamble consisting of a repeated 80 chip psuedo-random sequence is inserted into the data stream. This preamble is used by the receiving modem to adjust its own timing to that of the incoming signal prior to data demodulation.

The waveform requires that this timing be accurate to within 50 nanoseconds. This accuracy is achieved by adjusting the time of a locally generated replica of the preamble in 100 nanosecond steps until the signals match up or correlate. The number of steps employed is determined by the assumed maximum time error due to unknown range between the two terminals and drift between respective terminal clocks. For shipboard application, for which the SEACOM system was designed, this maximum error was specified as $\pm$ 1 millisecond. This requires a search of approximately 20,000 steps which are processed within the 1/2 second duration of the preamble. If the initial time error is greater than 1 msec. synchronization cannot be achieved by this process [4]. A description of how this initial clock accuracy of 1 msec. was accomplished is now explained.

The sources of time used for local operations were the Naval Observatory (via microwave link to Waldorf) and Loran C at Wright-Patterson Air Force Base. An experiment was also made with a GOES satellite receiver [5] (unfortunately the receiver was not available during most of the testing). The GOES receiver had the capability of acquiring a satellite broadcast time signal within two minutes after turn on. If the range to the satellite is known, this unit will provide timing with 1 msec accuracy. In a test at Wright-Patterson, the timing of this signal varied between 220 μsec and 260 μsec with respect to Loran C over a two day period.

The aircraft in this test program is a C-135 shown in figure 3 operated by the 4950th Air Test Wing. Power is normally not applied to the aircraft except for specified periods (of 4 hours or less) of ground testing or during flights. Access to the aircraft was via either a cargo hatch or a crew entrance ladder as shown in figure 4. The crew entrance ladder is the normal mode of entry to the aircraft. This modem was designed for shipboard use where power outages would be infrequent and relatively brief. The battery in the integral frequency standard was used to keep power on the clock circuitry to provide a "hot" turn on. The modem on the test aircraft was turned off overnight and during stopovers. Since the on-board battery power was not designed for such long outages, portable clocks were generally used to reset the time.

PORTABLE CLOCK

For overseas operations, time was maintained with a portable clock which was carried off the aircraft during stopovers. Figure 5 shows a typical overseas operation which illustrates the environment that the portable clock must survive for a successful experiment. It should be noted that the post flight battery operation is critical in that the clock must be removed from the aircraft by the experimenter who must then find a primary power source in an unfamiliar environment before the batteries discharge. Typically on overseas flights there are many operational, legal and bureaucratic details to be looked after before the experimentor can find prime power. It was typically very difficult to locate

a local source of precise time within the restrictions of limited stopover time, complicated logistics due to usage of crew buses and difficulty in determining precise time availability in advance. These comments apply both to U. S. Air Force bases and to overseas cities that were visited.

One other source of time that was used when possible was a time signal from the Lincoln Laboratory LES 8 satellite which was in synchronous orbit over the Pacific Ocean.

OPERATIONAL RESULTS

Figure 6 shows the flight path of a two week trip in September 1978. The trip started at Wright-Patterson Air Force Base on 12 September and returned home on 26 September. An Efratom Rubidium frequency standard was carried as a portable clock and time was successfully maintained during this trip. Figure 7 shows the specifics of the trip and the highlights of the portable clock log. The clock was set at Wright-Patterson using Loran C just prior to takeoff. This trip was typical of several in the test program. Various legs of the flight provided low elevation angles, high elevation angles, high relative velocity and a high multipath environment. Successful synchronization was achieved in these environments. The trip log shows a check with NASA at Ascension Island which was typical of attempts to verify the operation of the portable clock at stopovers. It took half a day of negotiations to obtain a ride to the NASA site (on the other side of the island). Figure 8 shows the main building at the site, which housed an HP Cesium Standard that was estimated to be within 25 μsec of UTC. Based upon known aging characteristics (figure 7) of the SEACOM portable clock, the SEACOM time was known to be within 10 μsec of UTC. Figure 6 also indicates a power disruption at Rio caused by a blown fuse when the portable clock was inadvertantly plugged in the wrong outlet. In Lima, Peru the aircraft was in range of the LES 8 satellite for the first time and a time check was possible which showed a time offset consistent with the drift rate measured on 7 September.

A number of clock synchronization techniques were attempted during the course of this program and they are listed in figure 9. The "Hot Turn-On" was the method of timekeeping intended by the manufacturer whereby the time was maintained by the battery in the integral frequency standard for short (less than 3 hours) power turn offs. A second technique was the use of a second clock with a compatible time code. Time could be transferred by connecting a cable between the two clocks. However, existing portable clocks usually do not have time code generators. These portable clocks can be used by manually entering the time via thumbwheel switches and synchronizing with a 1 PPS signal. If the accuracy of the portable clock was in doubt, a manual search could be made by offsetting the "range" control which can be varied in 500 Km/HR (2 msec) steps. This method could be very tedious and time consuming

since only one trial can be made during each 4 second frame. During the test program, a UHF satellite communications channel was available to relay test procedures and instructions. A "coarse" time calibration was occasionally used by having one operator "mark" his own time while the other noted his time. This technique was successful only when a precise 1 PPS signal was available. For local operation, it was occasionally possible to use a line-of-sight radio to a phone patch for the same technique. A feature designed into the modem, but never made operational, was for the transmitting modem to broadcast its own time code. The receive modem could then automatically acquire this time and reset its own clock.

RECOMMENDATIONS

A number of potential improvements to the SEACOM design could be implemented for operational military airborne satellite communications as shown in figure 10. The broadcast time of day could be a part of the network control that would broadcast a time code on a communications channel. This technique places the burden of synchronization on the transmitting source. The second approach provides the receiving operator with an optional mode that would permit a wide time search if synchronization were not achieved. This mode of operation is widely used in military communications networks and is generally referred to as a "net entry" mode, which is used by terminals which are entering the network for the first time or have had an extended outage. For example, a span of 1 second could be searched in 3 minutes with the existing equipment. A third technique would be to use a waveform that would be more tolerant of time offsets. Reduction of the PN rate would reduce the required synchronization time, allowing a larger initial time error to be accommodated in the short synchronization time. The last concept is more generalized and expanded in figure 11. This concept is primarily for test and evaluation efforts. The ideal portable clock would be capable of being carried in one hand across an aircraft parking area as well as up and down crew access ladders. It would be capable of operating on prime power anywhere in the world with automatic switching and tolerate the long delays between power down and access to prime power. It would interface with a serial or parallel time code "buss" (the specific type being determined by the system) and have the capability to measure the difference between an external 1 PPS signal and its own 1 PPS signal. Controls and indicators would be kept to an absolute minimum, particularly on the front panel. Reliability and price are also important considerations.

REFERENCES

1. S. A. Nichols, et. al., "Interim Test Report of the SEACOM Modem/ Radio," NRL Memo Report 4138, 1979.

2. E. M. Perdue, et.al., "Dual Frequency SATCOM Low Level Terminal AN/ASC 28," AFAL-TR-78-201, Dec 1978.

3. D. E. Kendall, "Development of the Defense Satellite Communication System - Phase II," EASCON '78 Record, IEEE Electronics and Aerospace Convention Record, Sep 1978, p. 458.

4. S. A.Nichols and D. G. Woodring, "Applications of Atomic Frequency Standards to SATCOM Spread Spectrum," 32d Annual Symposium on Frequency Control Proceedings, Jun 1978, pp. 555-559.

5. D. W. Hanson, et.al, "Time from NBS by Satellite," Proceedings of the Ninth Annual Precise Time and Time Interval Planning Conference, Mar 1978, pp. 139-152.

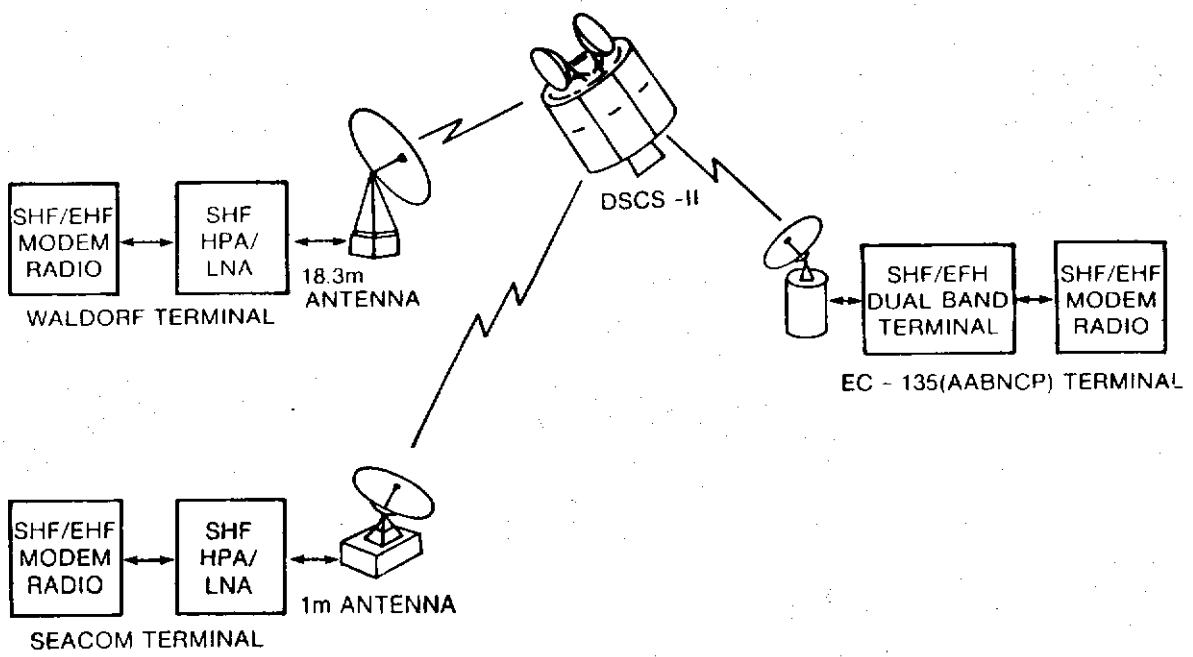


Figure 1. Test Configurations

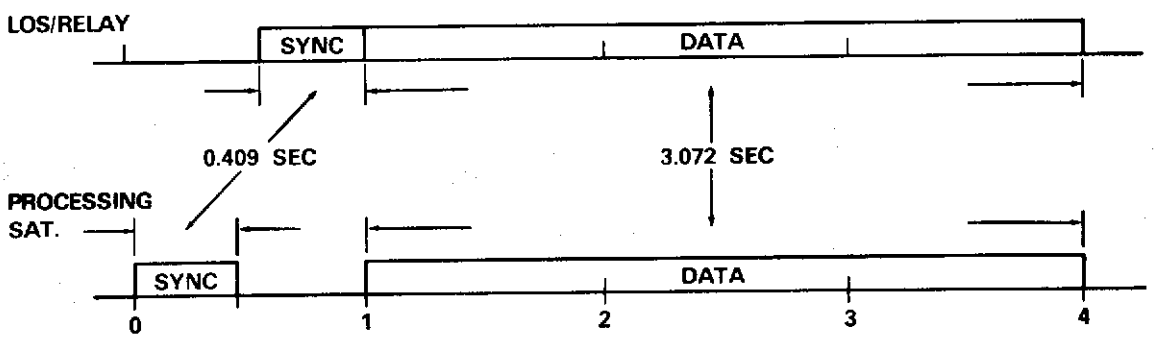


Figure 2. SEACOM Waveform: Time Slot Structure

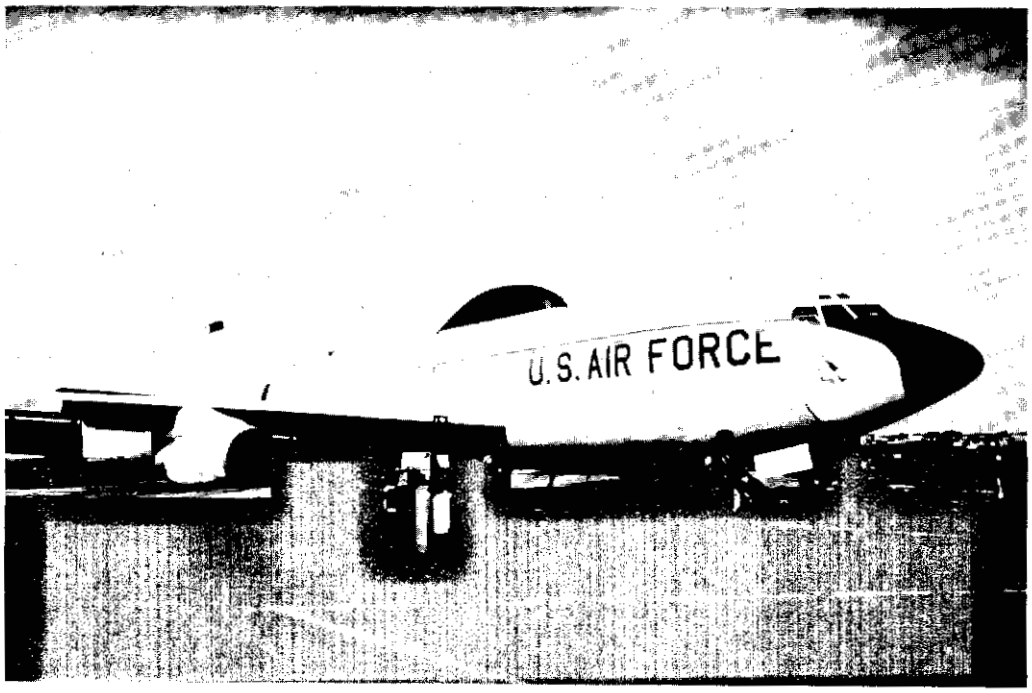
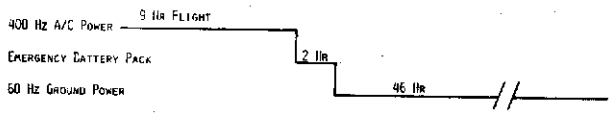


Figure 3. C-135 Test Aircraft

Figure 4. Crew Entry Ladder for C-135



Flight time - 9 Hours
Land-taxi 20 Minutes
Post flight Maint, debrief, wait for bus - 1Hour 30 Minutes
(Usually no power cart)
Bus ride to base operations - 15 to 20 Minutes
Getting permission to leave standard - 10 Minutes
Getting adapters, plugging in - 5 Minutes
Total ground time - 46 Hours

Figure 5. Typical Overseas RON Operation for Rubidium Standard

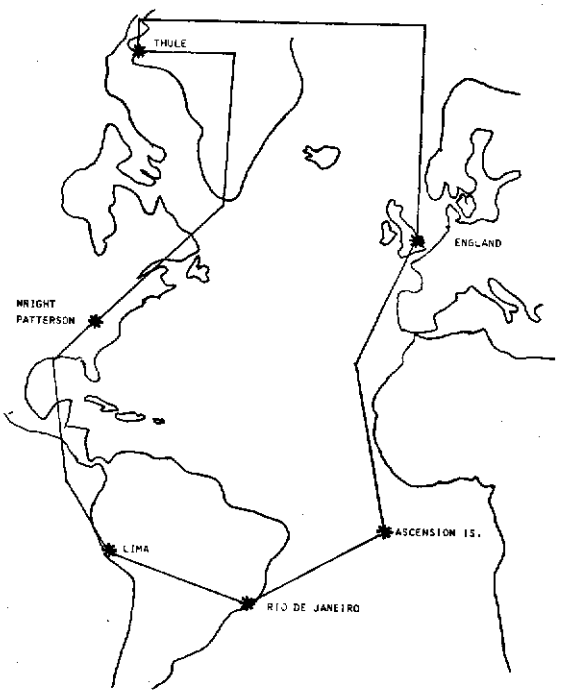


Figure 6. Overseas Test Flight Path

DATE	LOCATION	COMMENT
7 Sep	Wright-Patterson AFB	$\Delta\nu_E = -3.7\times10^{-11}$ (3.2 μsec/Day) set Rb
12 Sep	Leave Wright-Patterson	
16 Sep	Leave England	
18 Sep	Ascension Island	Check with NASA
22 Sep	Rio de Janeiro, Brazil	Power Disruption
26 Sep	Lima, Peru	-68 μsec to LES 8

Figure 7. Atlantic TDY Trip Log September 1978

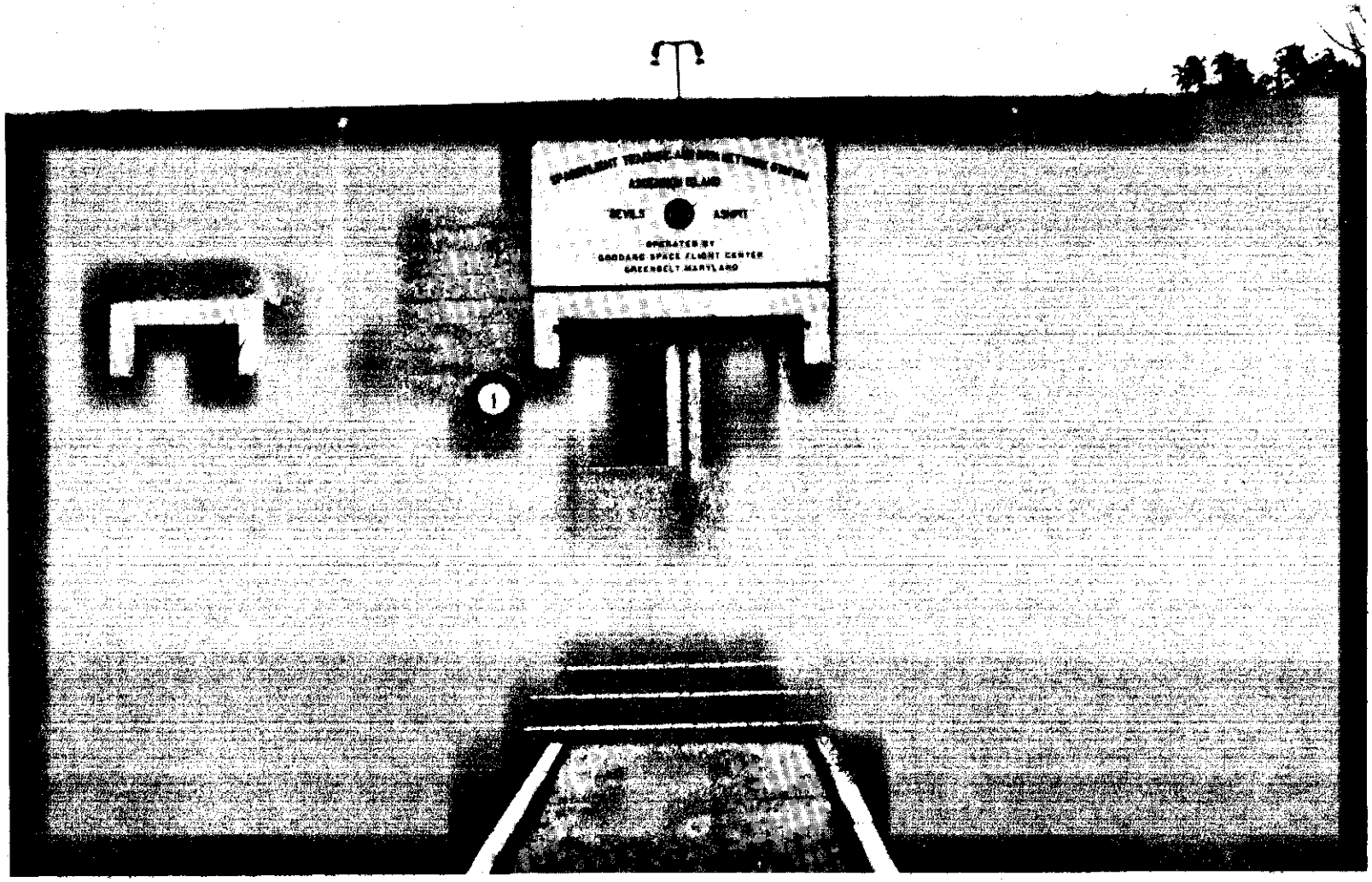


Figure 8. NASA ST DN Station at Ascension Island

- Hot Turn On
- Hardwire patch from Co-located Clock
- Carry on of Portable Standard from Remote Clock
- Time Search via Range Input Thumbwheel Switches
- Time Countdown via UHF SATCOM
- Time Countdown via Phone Patch
- Broadcast Time-of-Day Mode (Not Operational)

Figure 9. Initial Synchronization Techniques (In Order of Increasing Difficulty/Reliability)

- Broadcast Time-of-Day Mode
- Special Initial Synchronization Mode to Cover Greater Time Uncertainty (~± ½ second can be searched in 3 min)
- Reduced PN Rate on Waveform to Reduce Required Accuracy and Shorten Synchronization Time for a Given Time Error
- "Ideal" Portable Clock

Figure 10. Potential Improvements

WEIGHT	< 30 lbs per item
PRIME POWER	110/230 V ±20% 50 - 400 Hz Automatic Selection
STANDBY POWER	4 hrs @ Amb. Temp
OUTPUTS	1 PPS 5 MHz "BUSS" Time Code
INPUTS	1 PPS "BUSS" Time Code
DISPLAY	day, hr, min, sec Δ (1PPS)
INDICATORS	Absolute Minimum
CONTROLS	Absolute Minimum (none on outside front cover)

Figure 11. The "Ideal" Portable Clock

QUESTIONS AND ANSWERS

DR. STEIN:

I think there are several programs which require just such a device as your ideal portable clock. And I believe such a device is being procured for the MECON program. Is there any cooperation between these different groups?

DR. NICHOLS:

I would say no. Raytheon is currently building a SHF satellite communications terminal for airborne uses and they are developing a portable clock for that. And I had an opportunity to go to the design review a couple of weeks ago and that portable clock was developed-- and I think that was why I put my ideal portable clock ideas up, because they developed it out of their own experience without going to the community at large and I think they are going to have problems with that clock. It has too many bells and whistles on it and they tried to make it do too many things and when they get it in the field it is just not going to work. That was my experience that the more things that could go wrong, when you get out there in these remote locations, the more that do go wrong.

MR. CHARLES GAMBEL, Air Force Metrology Center

And you said you made these tests in 1978?

DR. NICHOLS:

Yes.

MR. GAMBEL:

You said you didn't have any time in Thule, Greenland--

DR. NICHOLS:

Now, you have to remember that I am in an operational situation. I am in an airplane that is coming into a strange location and we go into the operations center, and, you know, time could be available next door, but the question is, do I know about it. And this is a problem too. Does the left hand know what the right hand is doing. You are going to say time was available in Thule.

MR. GAMBEL:

Yes. Time was available at Thule to 10 microseconds, and also was available in Hawaii. I just couldn't understand why it wasn't made available to you.

DR. NICHOLS:

Well, in Hawaii we went to PMEL and all the guy had was a WWVH receiver. It is probably another case of, maybe in another building someone had better time, but asking at the operations center, which is the people we dealt with as a transient aircraft, that was what we had to work with.

MR. GAMBEL:

Okay. Thank you.

DR. FRED WALLS, National Bureau of Standards

Let me again reiterate a plea for commonality in cooperation so that one ends up with standardized building blocks of a common frequency. And the reason for that is something that you have pointed out, several other people have pointed out, and that is survivability and reliability. If you produce a clock, a portable clock, a clock that goes in JTIDS, CTOC, or whatever, the experience has been until you make many of those things, perhaps as many as a hundred, the reliability is going to be low. And so if you have several of these, perhaps in different sets, that are all in the same frequency, they can act as reliability buffers for you, so if you have a failure in one you can use the frequency of one in another, and you get a great deal more experience so that you have many, many units deployed in the field and we can learn some of the design flaws and hardware flaws in these.

DR. NICHOLS:

I guess that fairly well summarizes what I was trying to do; the main point of my presentation.

MR. KAHAN:

Just to reiterate what Dr. Stein was mentioning, a clock, if you argue ideal conditions is being developed and further beginning with the cesium, especially for the EC-135 to go up the full ladder, up and down, that is the exact application it is being developed for.

DR. NICHOLS:

It would appear that Raytheon isn't aware of that--

MR. KAHAN:

No.

DR. NICHOLS:

--because that is not the approach they are taking.

MR. KAHAN:

I don't know about the Raytheon clock and I am not aware of that, but a cesium clock is being developed for the EC-135, portable, less than 30 pounds and all the attributes that you listed.

MR. BILL PICKSTON, Ford Aerospace Communication Corporation

I would like to know who is developing that clock?

MR. KAHAN:

It was reported on at the Atlantic City conference last summer by Frequency Electronics.

SESSION II

OUTLOOK ON NEW TECHNOLOGIES

Dr. Samual R. Stein, Chairman
National Bureau of Standards