A black and white satellite photograph of Earth, showing a large body of water and surrounding landmasses. The image is taken from a high angle, showing the curvature of the planet. A white rectangular box is overlaid on the upper part of the image, containing the title of the report. In the top left corner, there is a small white rounded rectangle containing the report number. In the middle right area, there is a library stamp.

SSEC No.84.02.S1

Study of Advanced Microwave Sounding Unit to Determine
Optimum Methods of Data Compression

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A REPORT

from the space science and engineering center
the university of wisconsin-madison
madison, wisconsin

Study of Advanced Microwave Sounding Unit to Determine
Optimum Methods of Data Compression

A Report to

U.S. Department of Commerce

National Oceanic and Atmospheric Administration

for

Study of Advanced Microwave Sounding Unit to Determine
Optimum Methods of Data Compression

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1. Introduction

The Space Science and Engineering Center (SSEC) at the University of Wisconsin (UW) was contracted to conduct a preliminary design study of an on-board processor that compresses the high volume of raw data from the Advanced Microwave Sounder Unit (AMSU) into a manageable volume of radiance and/or meteorological parameters for real time transmission via the beacon transmitter. This study investigated the same problem for HIRS data and determined the trade-offs in processing only AMSU, only HIRS, and both together. This was done by analyzing the data stream, determining methods for handling the data, and evaluating possible hardware and software configurations for transmitting processed AMSU as well as HIRS data to VHF receivers on the ground.

The long lifetime of this contract was necessitated by the changing specifications for the AMSU instrument configuration. After considerable negotiations, the following instrument design was decided upon in late 1982.

The AMSU is to be a twenty channel microwave sounder. Channels 1 through 15 will have a field of view of 50 kilometers and will complete a scan line in 8.0 seconds. Each scan line will contain 30 individual fields of view. Channels 16 through 20 will have a field of view of 15 kilometers and will complete a scan line in 2.66 seconds. Each scan line will contain 90 individual fields of view. It is anticipated that the analog signal for each channel will be integrated for each field of view. This integrated signal will be digitalized into a 13 bit word. Field of view identification and housekeeping functions will add to this raw data output. It is estimated that channels 1 through 15 will have a raw data rate of 900 to 1100 bits per second. Channels 16 through 20 will have a data rate of 2400 to 2900 bits per second. The difference between minimum and maximum data rates is the unknown

amount of housekeeping data that needs to be outputted each second. The instrument will also be calibrated every scan line. A calibration consists of viewing space and viewing a warm (300°K) target. The estimated AMSU 4000 bits per second (bps) must be compressed into 1900 bps to fit onto the TIP beacon transmission. Table 1 summarizes the AMSU bit stream.

The HIRS is a 20 channel infrared sounder with a 30 kilometer field of view (at subsatellite point) which samples 56 fields of view within each scan line. The HIRS utilizes 2880 bps on the beacon path. It has been on the NOAA polar orbiters since 1978 starting with NOAA-6.

2. Data Compression Schemes

Initially our efforts were focused on understanding the requirements on the system and establishing viable approaches. To transmit the AMSU data efficiently over the beacon path, compression by more than a factor of 2 with about 0.1% precision must be achieved. The most likely approach to the data transmission is to have different levels of data reduction selectable by ground command. The choices would range from the simplest compression of the raw AMSU (and/or HIRS) data stream, without incorporating any transformations to physical units, to the more difficult reduction of the AMSU (and/or HIRS) raw data completely into meteorological parameters.

More specifically, four levels for the AMSU reduction were identified. They are:

(A1) Reduce the data volume by determining min, max, mean and rms for four continuous samples of data from three contiguous scan lines for each of the high spatial resolution channels (16 through 20). This makes the spatial resolution for these channels 45 km^2 and comparable to that of the other channels (1 through 15) at 50 km^2 . This accomplishes a factor of 1.7

reduction in the AMSU 4000 bps bit stream. The data from channels 1 through 15 are unaffected as are the engineering (housekeeping) data.

(A2) Calibrate the raw radiances radiometrically, convert to brightness temperatures, and then reduce the data volume by subtracting from each channel output a reference value corresponding to standard atmospheric conditions. Two standards, one for land and one for sea, were envisioned. Ten bits per word are necessary to achieve $.25^{\circ}\text{C}$ precision in the brightness temperatures, to accommodate a 128°K range of brightness temperatures, and to allow one bit for the standard indicator (land or sea). The reduction in the word length for each field of view (from 13 bits to 10 bits), yields a factor of 1.3 reduction.

(A3) Transform the data into a limited number (10) of meteorological parameters at 50 km^2 spatial resolution. Table 2 summarizes a possible set of parameters. This raises the number of 10 bit words per 50 km^2 field of view to 45 (1 each for channels 1 through 15, 4 each for channels 16 through 20, and 10 meteorological parameters). This represents an increase by a factor of 1.3.

(A4) Perform a differencing of scene brightness temperature data with respect to spatially adjacent elements along a scan line. Tests performed with simulated AMSU data indicate that a compression of 1.8 can be achieved in this step. The compression scheme used is described briefly in the Appendix.

For the HIRS data reduction similar software levels were identified. They are:

(H2) Same as A2 for AMSU. The reduction in the word length for each field of view (from 13 bits to 8 bits) yields a factor of 1.6 reduction in the HIRS 2880 bps bit stream. Eight bits were considered sufficient since the variability in scene temperatures is less than for the AMSU.

(H4) Same as A4 for AMSU.

In order to simulate onboard processing of AMSU data, it was necessary to create a realistic sample data set for input to the processing algorithms. The NOAA-6/7 MSU data, collected via the TIROS direct readout facility at SSEC, was considered to be the most appropriate data source. This was based on the assumption that the AMSU data would require similar processing tasks and would have many of the characteristics of the MSU data.

A summary of the compressions is found in Table 3. The raw AMSU bit stream cannot fit into the allocated beacon path; even with the addition of 10 derived meteorological parameters per 50 km² for it can be compressed to fit comfortably into the allocated beacon path. The raw HIRS bit stream fits into its allocated Beacon path; reduction of this bit stream by a factor of 3 is possible.

3. On-board Microprocessing Simulations

Since extensive 8080 software already existed for the extraction and collection of MSU data from the TIP data stream, an 8080-based microcomputer system was chosen as the test system on which the initial phase of the simulation could be performed. This choice is also supported by existing SSEC hardware in the form of an Intel MDS (Microcomputer Development System), which is well equipped and designed for the testing of 8080-based prototype microcomputers.

Software for the TIROS direct readout (8080-based) system, which was developed and tested by the NESDIS Development Laboratory in 1981 for collection of (NOAA-6/7) MSU data from 9-track magnetic tape has been modified and transferred to the MDS. This software, with the addition of several calibration algorithms, will run on the prototype system.

A data set of 23 scan lines of NOAA-6 MSU data was created and stored on flexible disc. Software was then developed, on an IMSAI 8080 microcomputer, for reading the disc and transmitting the data, one byte at a time at a selectable rate, over a serial link to the prototype system.

The prototype software was extended to include the determination of calibration coefficients, including the conversion of telemetry data to temperatures, and the application of these coefficients to the four channels of output for each scan line.

The software was then transferred to the prototype system consisting of an Intel SBC-80/10 CPU board, 32K of static RAM, and another board which provides the data input (serial) port. The tests completed indicated that the input and calibration of 4 MSU channels could be accomplished at an input rate of only about 225 baud. This limitation was imposed by the task of having to input the data under microprocessor control.

Since the tests using the SBC-80/10 showed that a faster processor was required, the then-new IBM Personal Computer (PC) with an 8088 CPU and 8087 Numerical Data Processor was considered for the task. The AMSU software was modified and installed on the IBM-PC with additional communications software which would allow the prototype onboard processor (the PC) to input data on an interrupt basis. The same data source (IMSAI 8080), via RS-232 serial link, was used. Figure 1 shows the microprocessor test configuration. Other additions to the previous software, which produced calibrated brightness temperatures, were:

- a) limb correction of brightness temperatures,
- b) statistical retrieval of atmospheric temperature profile,
- c) linear compression of brightness temperatures by differencing.

Using the IBM-PC, capable of approximately 3000 floating point operations per second (using code generated predominantly via the IBM FORTRAN compiler), the "zero level processing," i.e., generation of calibrated brightness temperatures as in previous tests, was accomplished at the maximum input rate of 9600 BAUD. This rate would more than satisfy the requirement of processing the 15 low frequency channels. Table 4 shows the maximum input rates for the four levels of computation. As Table 4 indicates, an onboard processor similar to the IBM-PC with 8087 coprocessor could process the data stream from the 15 low frequency channels, producing calibrated, limb corrected, linearly-compressed brightness temperatures. The additional load of the statistical retrieval of atmospheric temperature profiles would perhaps be possible if all code was optimized.

4. Conclusion

An onboard microprocessor could accomplish a considerable amount of preprocessing (and even processing) of the raw AMSU data. With a microprocessor of comparable capability to the IBM-PC, calibration, limb correction, conversion to brightness temperatures, statistical retrieval of temperature soundings, and compression by linear differencing of the processed bit stream are all possible. For similar processing of the HIRS data, a separate microprocessor would have to be incorporated. Unfortunately the available beacon path makes it impossible to send both raw and processed data; doubling the available beacon path would alleviate this problem.

It is very desirable to transmit calibrated brightness temperatures and derived meteorological parameters to users around the world so that a baseline standard is implemented and that the products are available to even modest users with only a VHF receiving capability. By performing the onboard

processing, accurate and uniformly consistent data sets can be available to the international community. By transmitting the information through the beacon transmitter, the satellite sounding technology would become affordable to many new users in developing countries. Only then can the positive impact of satellite information on existing weather networks be realized.

TABLE 1
AMSU RAW DATA BIT STREAM

5 HIGH FREQUENCY CHANNELS

(1 line)/(2.66 sec)
(90 fovs + 8 blackbody and space views)/line
(5 data words + 1 housekeeping word)/fov
(13 bits/word)

2874 bits/sec

15 LOW FREQUENCY CHANNELS

(1 line)/(8 sec)
(30 fovs + 8 blackbody and space views)/line
(15 data words + 3 housekeeping words)/fov
(13 bits/word)

1112 bits/sec

this adds up to

20 MICROWAVE CHANNELS

3986 bits/sec

TABLE 2
ON BOARD DERIVED METEOROLOGICAL PARAMETERS
FOR EACH 50 km² FIELD OF VIEW

1000-850 mbar thickness temperature

850-700

700-500

500-300

300-100

1000-700 mbar thickness relative humidity

700-500

500-300

Cloud Top Pressure

Liquid Water Content

TABLE 3
COMPRESSION TO BEACON PATH BIT STREAM SUMMARY

	AMSU	HIRS
Raw data	4000 bps	2800 bps
Uniform gridding	2400	
Reference to standard	1850	1770
Add meteorological parameters	2380	
Difference wrt adjacent fovs	1320	980
Available Beacon Path	1900	2880

TABLE 4
MAXIMUM INPUT RATES TO THE ON-BOARD PROCESSOR (IBM-PC)

<u>COMPUTATIONAL LOAD</u>	<u>MAXIMUM INPUT BAUD RATE</u>
Level 0: Brightness temperatures	9600
Level 1: Addition of linear compression	9600
Level 2: Addition of limb correction	6600
Level 3: Addition of statistical retrieval	2400

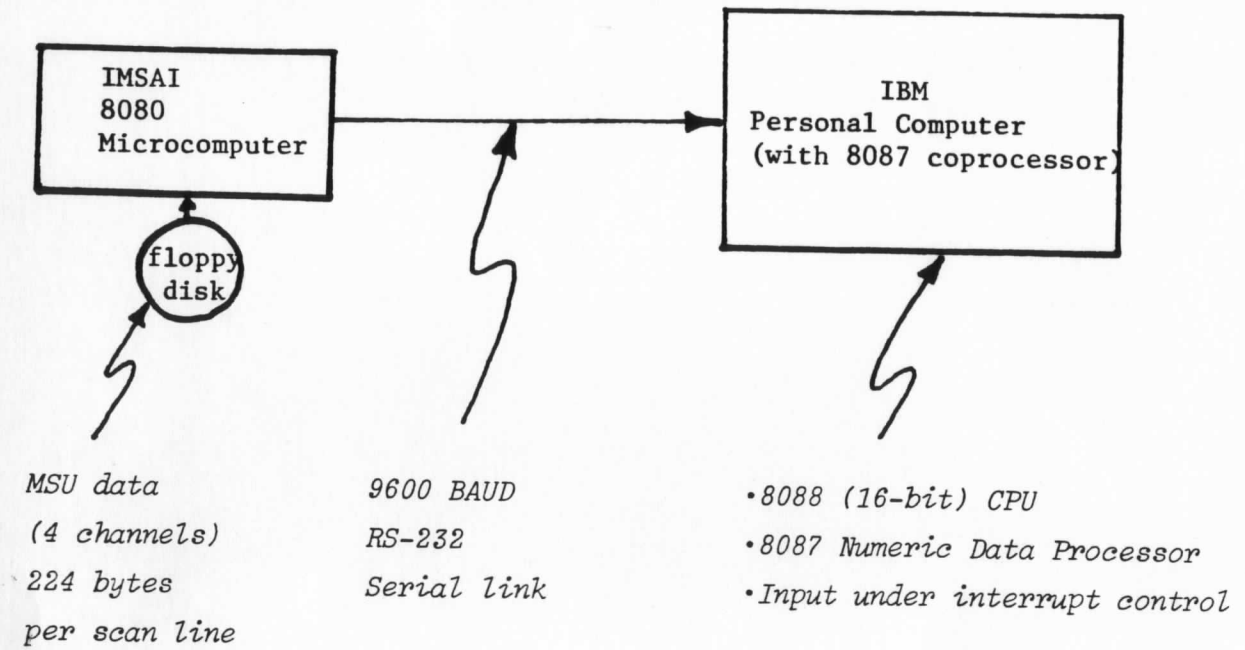


Figure 1: Microprocessor test configuration (version 2).

APPENDIX

Compression of Homogeneous Data

Homogeneous data refers to data consisting of a lengthy series of quantities all of which represent the same physical variable, and which have roughly comparable values. For example, a grid of 500 mb pressure heights make up a homogeneous set, since they all fall roughly within the range 4000-6000 meters.

The scheme used for testing transmission of compressed homogeneous data fields is as follows. The data are transmitted a row at a time, left to right, bottom row first. The transmitting program first scans the row to find the largest change from one grid point to the next, e.g., 47 meters. The program next determines the fewest number of bits needed to express the value 47, i.e., 6 bits, plus one additional bit because the increments from one point to the next may be either positive or negative; hence 7 bits. The program then transmits a 24-bit magnitude containing the full value of the left-most item in a row, e.g., 5271, followed by a 6-bit item containing the number 7 determined above, followed by a sequence of 7-bit bytes, packed end to end, representing the difference to be added to one grid value in order to obtain the next one. Thus, the first 7-bit byte contains an integer value to be added to 5271 to obtain the second grid value on the row, the second byte contains a value to be added to the second point to obtain the third, etc. The receiving program obtains the first full value from the initial 24-bit byte, and then successively accesses the following bytes to build up the entire row.