PART C

DATA MANAGEMENT

INTRODUCTION

The objective of data management is to provide a better data flow from the sensing of data to its application by the user. This effort is important because the data are increasing in complexity and volume, and the allowable time for reducing the data is limited in many instances. Data management should include, but is not limited to, the following: (1) onboard processing and transmission of the data to the ground, (2) ground handling and processing of the data, (3) machine interpretation of the data, and (4) distribution to the ultimate user.

As a major step in data reduction and in minimization of data-link bandwidth, as much onboard processing as possible should be performed within the practical constraints of the spacecraft or aircraft carrying the active microwave sensors.

A general block diagram of the data-management system is shown in figure 5–103 for a partial onboard processor. The figure traces the data flow from a sensor to the ultimate user.

Partial onboard processing will provide ephemeral data calibration, rough classification when appropriate, and as much bandwidth reduction as possible to reduce the telemetry load. Image restoration and registration will provide additional calibration when necessary, including geometric and atmospheric corrections, and will enter satellite ephemerides into the data. Image processing will provide enhancement, filtering, and, particularly in the case of SAR, the two-dimensional Fourier transform processing necessary to obtain the image. Pattern recognition and data compaction provide feature extraction, data classification, and, in many instances, conversion from image data to printed summaries. Data from the image-processing and pattern-recognition operation goes to either local or remote users.

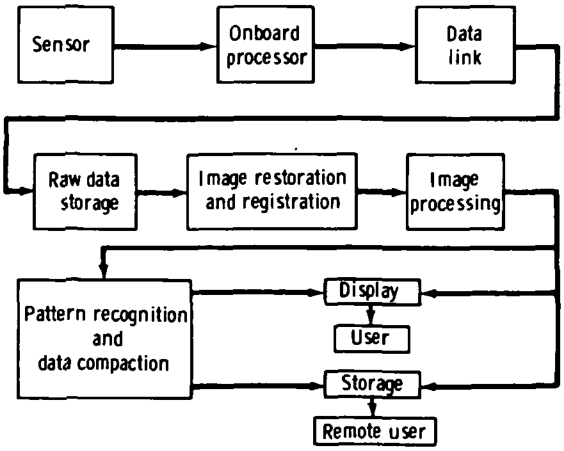

FIGURE 5–103.—Block diagram of the data management system for a partial onboard processor.

The approaches, equipment, and techniques are generally available for all functions shown in figure 5–103, except for the box labeled "Pattern recognition and data compaction." For research using satellite sensors, machine reduction is not necessary, and vast amounts of data are acceptable and even desirable. In this case, the effective data-management system on the ground must be an interactive system. Large computers alone cannot solve the data problem; thus, human interaction is needed to do the best research job.

The reverse is true in eventual operational usage. The managers, who must make decisions based on satellite data, will require inputs that are stripped of unnecessary information and are as compact as possible. For example, high-resolution radar maps of a region must be reduced to a table of hectares of wheat, rice, and so forth, together with an estimate of eventual yield for each. This function is the province of pattern recognition and data compaction. The techniques for accomplishing this task have not yet been developed for radar images and will require research effort.

The onboard processing and image processing required for SAR are discussed in the section entitled "Imaging Radar Data Reduction Considerations." The SEASAT–A ground data-processing system for radar images is a good example of an end-to-end data system and is discussed in detail in the section entitled "Imaging Radar End-to-End Data Systems." To illustrate how data may be processed for systems other than imaging radars, a brief discussion of the data handling and processing of the Skylab S193 altimeter, radiometer, and scatterometer is given in the same section.

Interpretation of the great mass of data that will be available from radar satellites requires at least partial automatic pattern recognition. Although much effort has been given to pattern recognition on other remotely sensed data, few results are available for active microwave systems. Hence, a specific recognition technique or data format cannot be suggested at this time. Appendix 5A to this chapter is devoted to a general discussion of pattern recognition with special reference to the active microwave data.

End-to-End Data System Overview

The term "end-to-end data system" is used to describe a system that converts analog radar signals into geographical quantities. The input "end" of the system is one or more analog signals from the radar, which, for most radars, would be a video-received output augmented with housekeeping information. The output "end" of the system is a measured geophysical quantity, which was estimated from some radar parameter. For example, the geophysical quantity could be significant wave height derived from the spread of surface echoes in an altimeter, windspeed derived from radar-scattering coefficient (which was derived from an echo power in a scatterometer), or ocean-wave spectra derived from a radar image. Between the input and output "ends" of this data system are other inputs such as ephemerides, instrument calibrations, housekeeping data, and propagation estimates. The propagation estimates may be provided by other space instruments.

The flow of radar data between the input and output is shown as the serial string of operations in figure 5–104. These functions are divided into two distinct groups. The first group includes functions performed on the spacecraft that transform the analog signal into a digital bit stream, a convenient form for storage in the spacecraft for eventual transmission to the ground.

The second group consists of the ground-based processing functions that begin with stored telemetry data and gradually convert the radar signals to geophysical quantities. Generally, the radar signals would be manipulated first and then converted to geophysical quantities using calibration curves. Once converted to geophysical quantities, the data would be distributed to users and archived for future data reductions.

The specific design of an end-to-end data system depends on the radar measurements flowing out of the instrument and the manipulations and algorithms required to convert these radar measurements to geophysical quantities. In some cases, like SEASAT–A, other instruments are flown and operated simultaneously, and several of the end-to-end data systems (like the one shown in fig. 5–104) must be tied together into an even larger system. However, in this section only single radar systems are considered.

The end-to-end data systems will depend

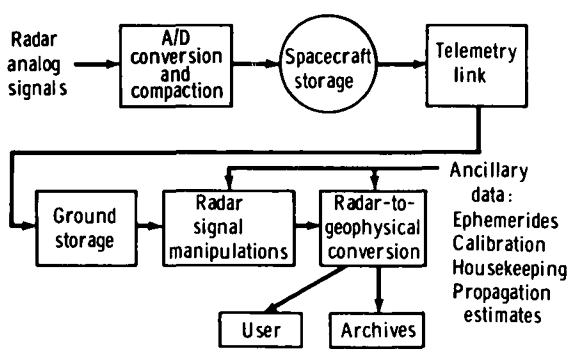

FIGURE 5–104.—Block diagram of an end-to-end data system.

on the number of spaceflights that a particular instrument has flown. For an instrument with no spaceflight experience, such as the imaging radar, many intermediate data products will be produced to ensure that individual processing steps are not breaking down. Also, the algorithms for converting radar measurements into geophysical quantities will be relatively crude. For other instruments such as radar altimeters and scatterometers, which have already flown in space, these algorithms will be more sophisticated and will be applied earlier in the data-processing chain, possibly onboard the spacecraft.

IMAGING RADAR DATA REDUCTION CONSIDERATIONS

Imaging radars have been proposed for SEASAT–A and Space Shuttle missions. Starting with a digitized version of video-amplifier output and ending with a digital-bit stream into an onboard storage, the data flow for an imaging radar requires that large volumes of data be reduced to maximize the output of radar instruments.

Synthetic Aperture Radar Data Acquisition

Synthetic aperture radar systems have generally gathered the data and recorded them for future processing on a ground-based correlator because the data-reduction process has not been amenable for real-time processing. With the advent of integrated circuits, especially large-scale integrated circuits, the possibility of digitally generating an image in real time with an onboard processor has become a reality.

A possible advantage of real-time processing of radar data onboard the spacecraft is that the total data content may be reduced if image data compression is used, thus eliminating one of the steps required to get the data to the user. However, a real-time processor still requires a complex piece of hardware that will require extra power and weight, and it may be more costly than an equivalent ground-based data digital correlator.

The synthetic aperture side-looking radar generates an image of the surface being observed by transmitting a coherent signal to the surface at a periodic rate and observing the return from all the resolution elements. During the data-reduction process, the two-dimensional data are passed through a two-dimensional matched filter corresponding to the ideal return from each cell. The following section describes the steps required to process these data digitally as an aid to determine at which point it would be best to stop the process onboard the spacecraft and to introduce the ground-based data-handling process.

Data-Reduction Processes

The data gathered by the coherent radar system may be thought of as being two dimensional. The first dimension, range, corresponds to the succeeding returns from a transmitted impulse and the echoes arriving from reflectors at increasing range. The second dimension, azimuth, corresponds to the returns at a constant range or time delay from succeeding pulses as the spacecraft travels in its trajectory. In a coherent system, the return from a single reflector is complex because it contains phase information and amplitude. The phase is relative to the constant stable LO and depends on relative delay in terms of fractional wavelength of the reflector. The amplitude is proportional to the transmitted waveform and the reflectivity of the target. The two-dimensional history of these returns uniquely determines the relative position and amplitude of this target relative to the radar system.

To obtain fine resolution in the range dimension, it is desirable to transmit a short rf pulse and receive through a wide-bandwidth receiver. Thus, one of the data reduction steps is pulse compression (i.e., range compression). A second process is azimuth compression, which corresponds to generating a focused synthetic array. Two other steps that may be performed are presumming and multiple-look processing. Presumming is an operation in the azimuth dimension to reduce the azimuth bandwidth. Presumming simplifies the data processing and reduces memory storage requirements at the expense of azimuth resolution. Multiple-look processing involves generating separate images from independent data and superimposing these independent images to reduce the speckle caused by the statistical variation of the returns from each reflector. This section will examine the data contents at each step and estimate the complexity of each operation.

The basic radar data processor configuration is shown in figure 5–105. This processor need not be on the spacecraft and may be broken up at any of these basic blocks. Consequently, four options exist: (1) basic processing on the ground, (2) presumming onboard the spacecraft and range and azimuth compression on the ground, (3) only azimuth compression on the ground, and (4) all processing onboard the spacecraft. For a system with multiple looks, a fifth option exists: transmitting to the ground the composite image rather than the individual components. This technique will be discussed elsewhere in this chapter.

The data rate out of the radar N_A may be expressed as

$$N_A = \frac{2N_b(T+\tau)c(\text{PRF})}{r_r} \qquad (5\text{–}56)$$

where N_b is number of bits per sample, T is

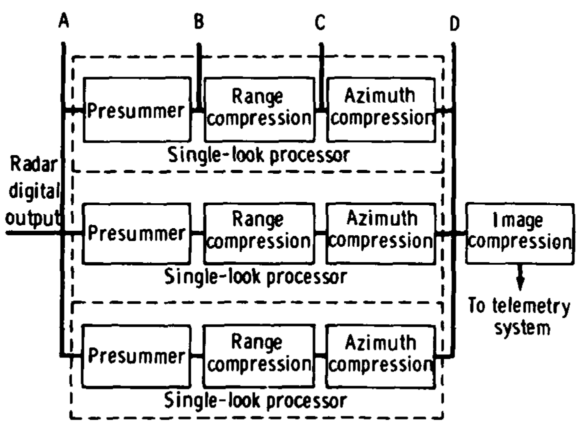

FIGURE 5–105.—Basic radar data processor configuration.

required sample interval in radar time, τ is dispersed transmitted pulse width, c is speed of light, and r_r is range resolution.

This equation may also be expressed as

$$N_A = 2N_b \frac{S_r S_a}{r_r r_a}\left(1+\frac{\tau}{T}\right) \qquad (5\text{–}57)$$

where S_r is radar space swath width, S_a is length images in 1 sec in azimuth, r_r is range resolution, and r_a is theoretical azimuth resolution. Because no processing has been done at this point, the theoretical azimuth resolution is

$$r_a = \frac{L_a}{2} \qquad (5\text{–}58)$$

where L_a is the antenna length along the velocity vector.

The presummer consists of several data storage arrays where a number of echoes are added on an ensemble basis, with or without time weighting. The presummer reduces the azimuth bandwidth at the expense of azimuth resolution. This azimuth bandwidth reduction also increases azimuth ambiguities. To reduce these ambiguities to acceptable levels, it is necessary to effectively oversample the azimuth data to a level higher than Nyquist's criteria by a factor K, varying from 1 to 2. Thus, after the presummer, the data rate N_B can be expressed by

$$N_B \quad \frac{2N_b T\left(1+\frac{\tau}{T}\right) vK}{r_r r_a'} \qquad (5\text{–}59)$$

where v is the spacecraft velocity, K is an oversampling factor, and r_a' is the desired azimuth resolution. Alternately, this expression may be written as

$$N_B = 2N_b \frac{S_r S_a}{r_r r_a'}\left(1+\frac{\tau}{T}\right) K \qquad (5\text{–}60)$$

The number of bits per sample N_b will be the same as before presumming, because no compression has taken place in either domain.

The range compression in the data system consists of a cross-correlation device. The effect is to compress the returns of the range-dispersed echoes. Because of the pulse-compression effect, the data will now have an increased dynamic range (not signal-to-noise). The increase in dynamic range is given by

$$N_c = \log_2 (\tau B) \qquad (5\text{–}61)$$

However, the data stream per azimuth line is shortened by the dispersion length τ. The data rate at point C, shown in figure 5–105, of the range compression subsystem is

$$N_c = \frac{2(N_b+N_c)\,TcvK}{r_r r_a'} = 2(N_b+N_c)\frac{S_r S_a}{r_r r_a'}K \qquad (5\text{–}62)$$

The azimuth compression subsystem is a cross-correlation device in which the signal is cross correlated on an ensemble basis with the azimuth-matched filter. Like the range compression subsystem, the dynamic range of the output will be greater than that of the input. The increase in dynamic range, in bits per sample N_d, is given by

$$N_d = \log_2 (TB_a) \qquad (5\text{–}63)$$

where T is the time the radar signal from a point reflector retains a Doppler frequency with a bandwidth B_a. In addition, the azimuth correlator will convert the data to baseband if a range offset occurs or if the data are in a complex mode (I and Q channels) computing the magnitude of the vector. In either instance, the output data content is

$$N_D = (N_b+N_c+N_d)\frac{S_r S_a}{r_r r_a'} \qquad (5\text{–}64)$$

At this point, the image may be formed directly where each pixel is characterized by $(N_b+N_c+N_d)$ bits per point.

The data storage DS required in the azimuth correlator is

$$DS = (N_b+N_c)\frac{S_r R_s \lambda}{r_r r_a'^2} \qquad (5\text{–}65)$$

where R_s is the range to the surface and λ is the radar system wavelength.

A radar image of a two-dimensional uniform target field processed with a two-dimensional matched filter will exhibit a variation of intensity in the output image from one resolution element to the next. This variation in apparent intensity is due to several factors such as (1) additive random noise caused by the radar system, (2) energy spillage from one resolution element to the next, and (3) variation of the apparent reflectivity of the resolution element with respect to angle of wave incidence. The latter term has been referred to as the reflection pattern of the target. The first factor is minimized by illuminating the target with sufficient power so that the signal-to-noise ratio is large. The second factor can be minimized by careful system design and by processing the data with suitable weighting functions to minimize both range and azimuth side lobes. Minimization of the third factor requires looking at the surface with either different wavelengths or different look angles; hence, the concept of multiple-look processing.

Multiple-look processing, to reduce image speckle, can be implemented using a variety of methods. These methods depend on either observing the terrain at several frequency bands or observing the terrain in different portions of the antenna beam. The first method is often referred to as obtaining multiple looks in range, whereas the second method is referred to as obtaining the multiple looks in azimuth. In either case, the image is generated by using these methods independently. The resultant signals are then noncoherently added. The result of this noncoherent addition is a more pleasing image because of the reduced speckle. This image is obtained by reducing the standard deviation of a uniform target field, which allows a more precise estimation of the surface backscatter coefficient. The improvement in image quality is not obtained without a price. If the different looks are obtained in range, the average transmitted power must be increased by the square root of the number of looks required, and the radar-receiver complexity is somewhat increased over the single-look case. If the looks are obtained in azimuth, the average radiated power is reduced by the square root of the number of looks, but an image buffer must be added to the multiple processors. The total data storage in this image buffer N_{buf} is given by

$$N_{buf} = (N_L - 1)\,(N_b + N_c + N_d)\,\frac{S_r}{r_r}\,\frac{3R_s\lambda}{2(r_a')^2} \qquad (5\text{–}66)$$

where N_L is number of looks.

Images have been successfully compressed to the extent that the total data transmittal is reduced by a factor of 30 to 50 from the uncompressed case. The impact of the image compression technique on the question of onboard radar data processing is very significant. A comparison of the basic (one look) processor data output and the radar system digitized data output (eqs. (5–64) and (5–58)) indicates that, for high-resolution processing, the data rate out of the processor may be no lower than if the data were telemetered back to the ground and processed. However, if an image compression technique were used, a significant reduction in data rate could be achieved by processing onboard the spacecraft. If the desired resolution of the imaging system is significantly worse than the theoretical resolution of the radar systems, the best point for data transmission to the ground may be at the output of the presummer (point *B* of fig. 5–105). At this point, for a given set of processing parameters, the data rate for the basic processor is at a minimum.

An examination of equation (5–65) gives an indication of the complexity of an onboard data processor for a spacecraft imaging radar system. As an example, the total data storage required for a radar (at an orbital altitude of 200 km, imaging a large swath width of 100 km, at a long wavelength of 0.2 m, and a resolution of 10 m) is approximately 32×10^6 bits. The current state of the art of shift registers suitable for a processor will store 4096 bits per chip. This processor would require 7800 integrated circuits. In the near future, charge-coupled-device digital shift registers are expected to have a significant effect on the digital processor implementation. Shift registers of 64×10^3 bits of storage and consuming two to three orders of magnitude less power are expected, making the digital processor a realizable device.

IMAGING RADAR END-TO-END DATA SYSTEMS

A purpose of the end-to-end data system is to transform data that are in engineering quantities into data that are in geophysical quantities. For an imaging radar, the starting data form is a two-dimensional array of power as a function of the orthogonal dimensions of range and azimuth. Azimuth is the along-track dimension and is a function of vehicle position as compared to time. The end data product will be some geophysical quality, such as wave spectra, as a function of position and/or time. Between these two end data products is a multiplicity of operations.

The End-to-End Data System for SEASAT–A

To better describe the end-to-end data system, the example of the SEASAT–A imaging radar will be used. The SEASAT–A, planned for launch in 1978, will have an imaging radar that will sample ocean surface phenomena in several modes. Sampled scenes with a wide swath of approximately 100 km (at a 25-m resolution) or 200 km (at a 100-m resolution) will be taken until the onboard storage of 10^9 bits is filled. Also, for global ocean-wave monitoring, patches 10 by 10 km (at a resolution of 25 m) will be taken at approximately a 100-km spacing until the onboard 10^9-bit storage is filled. In all these sampling modes, the radar data will be thinned by the presumming techniques described in the section entitled "Data Reduction Processes." The thinned data will be telemetered to the group and stored on telemetry tapes. These telemetry tapes will be processed to produce a radar image. This image is a convenient breakpoint and can be called the instrument output, and it is the input to the end-to-end data system. Figure 5–106 shows the end-to-end system for SEASAT–A.

This radar image resembles space photographs obtained with Mariner, Pioneer, and ERTS spacecraft. Both digital and analog radar outputs are planned for SEASAT–A. The analog output is the familiar photographic radar image. The digital image is a collection of bits on magnetic tape, which are similar to the downlink products of the Mariner, Pioneer, and ERTS spacecraft.

These two radar image products, the analog photograph and digital tape, can be derived from two nearly independent processing paths. An analog path would proceed where telemetry tape was converted to a signal film, which would be compressed in an optical correlator to produce an image photograph that could be digitized to produce a digital image tape. The alternate digital path would directly correlate the telemetry tape data in a digital computer to produce the digital image tape, and a photographic playback would produce the photographic analog image.

These two products represent echo power as compared to range and azimuth. Obvious data transformation to more useful products would include conversion of range and azimuth to latitude and longitude and conversion of echo power to normalized surface cross section.

In addition to location tagging, time tags must be carried. Time tags will probably be carried from the initial telemetry tape. Also, during this image processing, obvious data dropouts and other radar flaws will be corrected.

Like the original images, the corrected

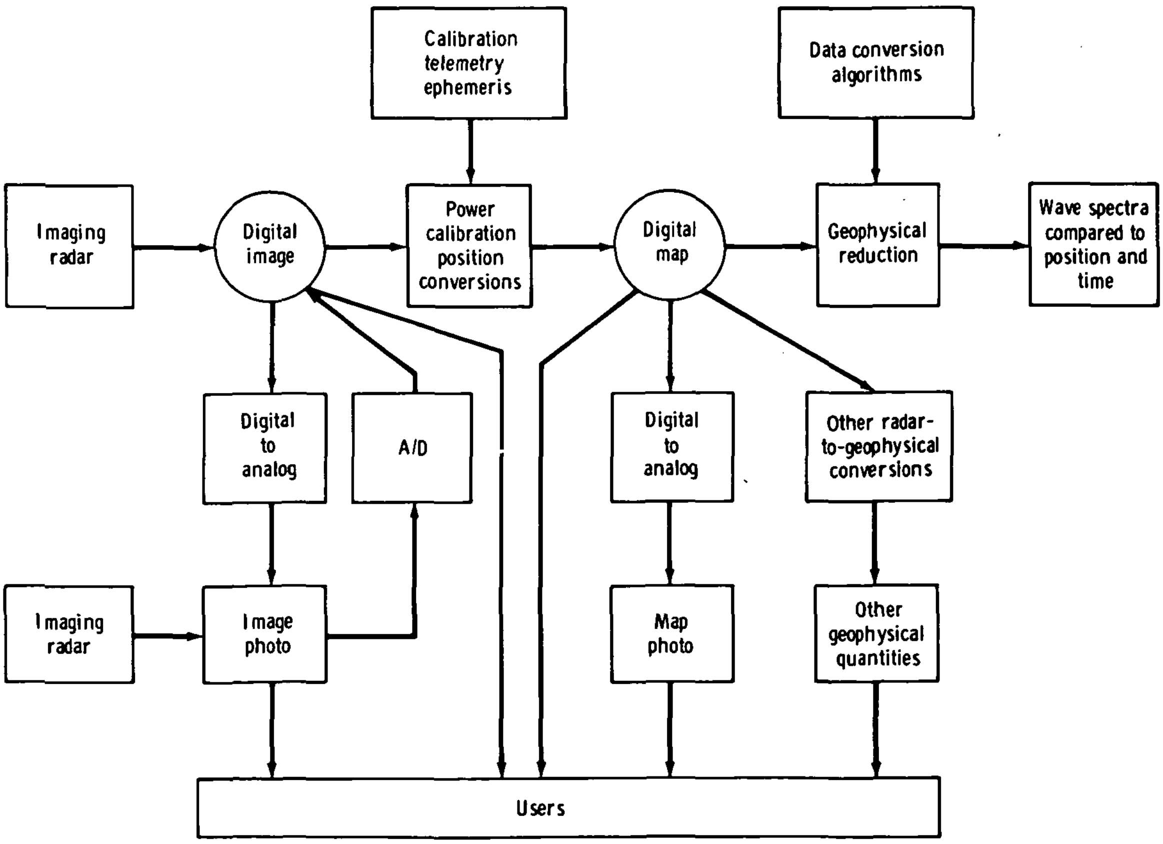

FIGURE 5–106.—End-to-end data system for SEASAT–A imaging radar.

and refined radar maps will be preserved as a digital image on magnetic tape. To separate the converted product from the original product, the term "map" is used for the corrected product, whereas the term "image" is used for the original product.

More processing will be needed to convert the mapped radar cross section to useful geophysical quantities. For example, a major objective of SEASAT–A is to convert these radar maps into wave spectra in a two-dimensional ocean wavelength space.

This example of SEASAT–A processing is illustrative of typical numbers for an imaging radar system. For example, the sampled swath with a 100-km width and 25-m resolution is 4000 pixels wide. Assuming images and maps of equal widths and lengths, there will be 4000 by 4000 radar pixels for a SEASAT–A frame as compared to 2400 by 3600 radar pixels for a single ERTS frame. Assuming eight bits per pixel, each picture has 1.28×10^8 bits (about the capacity of a standard computer tape). Photographic playback at a 15-μm spacing yields 60- by 60-mm negatives. For both ERTS and SEASAT–A radar imagery, the actual image length may be several times the image width, but these images can be reduced to square formats.

Several important points can be made by briefly reviewing this example of the SEASAT–A end-to-end data system.

1. The radar image data are similar to the photographic products from other spacecraft such as ERTS, Mariner, or Pioneer.
2. The user data products can occur at several points along the processing chain.
3. The radar parameters and/or operations can also enter at several points along the processing chain.
4. It is particularly important to have two types of products: the digital tape, which is the basic storage medium for the computer, and the photographic playback.
5. The ground-based processing must be flexible enough to accept new algorithms for computing geophysical quantities.

Other NASA radar imaging systems for the next decade will include aircraft test beds, possibly routine commercial aircraft, and the Space Shuttle. For the aircraft test beds, the data-processing steps outlined in figure 5–106 will be tested and proved, but a fixed and final system will probably not be built. However, if an imaging radar were built to operate routinely from a commercial aircraft, then an end-to-end data system similar to the one shown in figure 5–103 for SEASAT–A would be required. When imaging radar systems are carried onboard the Space Shuttle, an end-to-end data system will also be required. For the Space Shuttle flights, the end-to-end system must be flexible enough to keep up with changes in the Space Shuttle radar configurations, which will probably be improved with each Space Shuttle mission.

End-to-End Data Systems for Other Radar

Although not as complicated as a system for an imaging radar, end-to-end data systems for other radar types still require a degree of complexity. Figure 5–107 is a simplified flow diagram of the Skylab S193 altimeter, radiometer, and scatterometer.

This experiment was part of the Earth Resources Experiment Package (EREP), which combined several sensors. A combined data system was used to collect and record the data onboard the spacecraft. The basic flight-recording medium was a 28-track pulse-code-modulation tape recorder, and the tapes were returned by the crew after each mission. Once the tapes were recovered, a central data-processing system at JSC was used to reformat the tapes and correct any skew error that might have occurred. Fourteen-track tapes were then generated for each EREP sensor. These tapes contained essentially the raw experiment data. The data were used to assess experiment performance during the mission. The 14-track tapes were then subjected to further processing, which was unique to each experiment.

Altimeter data were time- and altitude-corrected with the Skylab data from the spacecraft. Altimeter calibrations and ephemeris correlations were input. Finally,

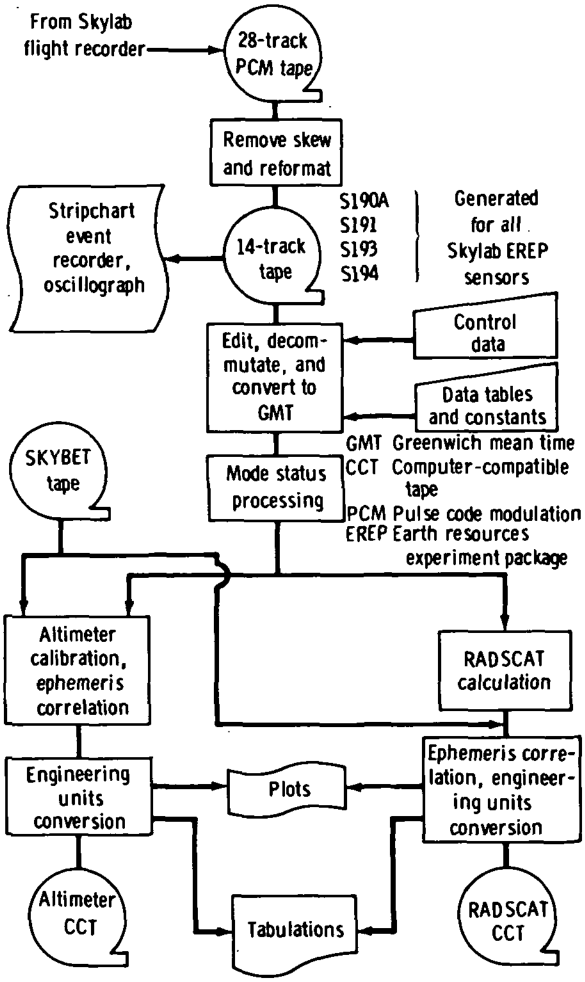

FIGURE 5–107.—Simplified diagram for data flow of the Skylab S193 altimeter, radiometer, and scatterometer.

engineering unit conversions were performed, and the information was recorded on a computer-compatible tape. In addition, plots and/or tabulations are generated as required.

The RADSCAT data received slightly different processing because certain calculations performed on the data were prerequisites to ephemeris correlation and conversion. The final output was a computer-compatible tape product. Plots and tabulations were also generated as required.

End-to-end data processing for altimeters, scatterometers, and radiometers may require several data reformats, attitude and time corrections, and calculations. The Skylab S193 experiment contained all three activities.

COMPUTER RECOGNITION CONSIDERATIONS

An important aspect of the conversion of radar measurements to geophysical quantities is the generation of fast and accurate algorithms. Interpretation of imaging radar data could require some form of pattern-recognition techniques in the image processing, and such techniques are useful to other radar data such as those from scatterometers, altimeters, and so forth. A discussion and techniques are presented in appendix 5A to this chapter, entitled "Pattern Recognition Considerations."

SUMMARY

The data management for a spacecraft radar has been defined in terms of an end-to-end data system, which performs the following three functions:

1. Sampling and compaction of data onboard the spacecraft.
2. Manipulation of radar data on the ground.
3. Conversion of radar measurements to geophysical quantities by means of pattern recognition and other machine techniques.

Division between these three functions is not always clear; and, as instruments are flown on more missions, the functions originally performed on the ground will eventually be moved closer to the data source and may in time be performed onboard the spacecraft.

The data processing for imaging radar onboard the spacecraft was examined in detail with the conclusion that several techniques can be used to compact the data before storage. The recent design study for the SEASAT–A imaging radar indicated that this data compaction was one of the outstanding research results in the design. It is recommended that compaction techniques be studied further and that existing aircraft radars be modified to provide digital data so that these compaction techniques can be tested.

Data management for SEASAT–A imaging radar provided an example of a possible end-to-end data system for a future spacecraft imaging radar. This example indicated that—

1. A radar image is similar to the photographic products from other spacecraft such as ERTS, Mariner, and Pioneer.
2. The user products and the radar parameters enter the processing at several different points in the system (i.e., the ends of an end-to-end system are not singular points).
3. Two basic data products must be considered: computer digital tapes and analog photographs.
4. Ground processing must be flexible and adaptive.
5. A library for radar data is needed.

Automatic computer-processing and pattern-recognition techniques must be implemented near the user end of an end-to-end data system. The applications of these processes to imaging radar data will expand, based on previous work with multispectral data.

PART D

PROGRAM PLANNING

This section presents a discussion and recommendations for future activities necessary to support satellite microwave sensing. The need exists for a program that will provide information in the following areas:

1. Experimental test program to establish the interaction of electromagnetic waves and sensed parameters.
2. Component development.
3. Data processing.
4. Calibration.
5. Design and fabrication of a multifrequency system.

Each area will be discussed in greater detail in the following paragraphs.

Inputs to this section were obtained from joint discussions between the TSG and the three panels of the Active Microwave Workshop.

EXPERIMENTAL TEST PROGRAMS

A requirement exists to determine experimentally the characteristics of surface features when these features are sensed by electromagnetic waves in the microwave portion of the spectrum. The stated desires and requirements of the Earth/land panel for experimental data from controlled tests were adequate to keep several aircraft systems busy on a continuous basis.

Earth/Land

The Earth/land panel has suggested an aircraft research program the objective of which would be to provide the information that has been lacking or fragmentary in this important field of remote sensing. Two additional items are highlighted for future effort: small-scale surface-texture measurements and polarization signatures.

Small-scale surface texture.—The unique capability of active microwave systems to detect variations in surface texture of geologic materials is potentially one of the most useful applications of microwave remote sensing.

A recent example of the type of detailed feasibility study necessary for a thorough examination of SLAR surface texture analysis is included in the section entitled "Com-