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DIGITAL CONTINUUM RECEIVER
USERS' MANUAL

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DIGITAL CONTINUUM RECEIVER: OPERATING INSTRUCTIONS

J. Richard Fisher

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DIGITAL CONTINUUM RECEIVER: OPERATING INSTRUCTIONS

J. Richard Fisher

Chapter I

INTRODUCTION

Operation of the Digital Continuum Receiver (DCR) is designed to be reasonably self-explanatory, so for many observations you may not need to refer to this manual at all. The first part of this manual is almost a step by step description of what an observer would go through in setting up the DCR, but this is intended to be a preview for the new user rather than a detailed instruction set. Of course, not everything can be made obvious with a limited amount of CRT display, and some things that seemed self-evident to the designer may not be to the user, so the written description may help explain the more cryptic points.

The order of the chapters to follow is roughly one of increasing complexity and detail. Occasional users will probably concentrate on Chapter 2, and the more frequent or inquisitive user may want to read through to the back cover. There is a brief glossary of possibly ambiguous terms at the end of the manual. Each of these terms is underlined the first time it appears in the text.

You will probably find the DCR in one of three operating conditions: 1) running in an <u>idle mode</u> ready for observing with a setup from a previous observer or one created by the telescope operator or receiver engineer, 2) connected to the receiver front end but either no display on the CRT of the DCR calculator or a prompt to select a new or old program as in Figure 24, page 39, or 3) completely disconnected from the front end and telescope computer. The first condition is the most probable, so it will be discussed first followed by 2) and 3). Let the table of contents be your guide on where to start in the text. Since the path through the setup and operating program will depend on choices made along the way, the steps are numbered so that branches and returns can be made in the text. This may be more confusing to read than to do.

Before leaping into the details, a few words about special function keys upon which much of the user interface is based. The DCR processor is an HP9826 desktop computer which we will distinguish from the telescope computer by calling the 9826 the calculator. It has a keyboard, a 50 character x 18 line text CRT with 300 x 400 pixel graphics, and a 5 1/4" floppy disk. On the keyboard are ten special function keys labeled k_0 through k_9. These are defined in the software, and their definitions are displayed on the bottom of the CRT just above and in line with the keys. The definitions may be answers to questions, requests for information or control of DCR functions, and the definitions will often change as a result of your actions. Since only eight characters are available for definitions, some of them may be a bit cryptic, and a fuller description in the text of this manual may be helpful. An index of special function key definitions is given in Appendix IV.

Chapter 2

OPERATING PROCEDURES

Normal Operation after Setup

Once the DCR has been configured to match the receiver front end requirements, it has two modes of data handling: an idle mode in which all of the calculations of the detector data are performed, but no data are sent to the telescope computer, and a scan mode where data are sent to the computer. The scan mode is initiated by a start scan signal from the telescope computer, and "SCAN IN PROGRESS" will appear on the CRT. A scan is terminated by a stop scan signal at which time the DCR will return to the idle mode. Except for a few drastic actions such as pressing the [PAUSE] key you are prevented from intervening in the DCR operations during a scan, but in the idle mode you have full control from the keyboard.

STEP 1

Normal idle mode control and displays.

In the idle mode you will see one of the displays in Figure 1 or 2. These are recirculating graphic displays of the last 360 data values, either all parameters for one receiver channel or differential antenna temperature data only for all channels. The data, Tsys, and gain graphs use an offset which sets the first data point to zero to keep them on scale on the average. If an errant first point has sent one of the graphs off scale the display may be restarted by pressing the [C.R./CRT] key and, then the [CRT] key in step 4, Figure 5, and then the [RESUME] key of step 6.

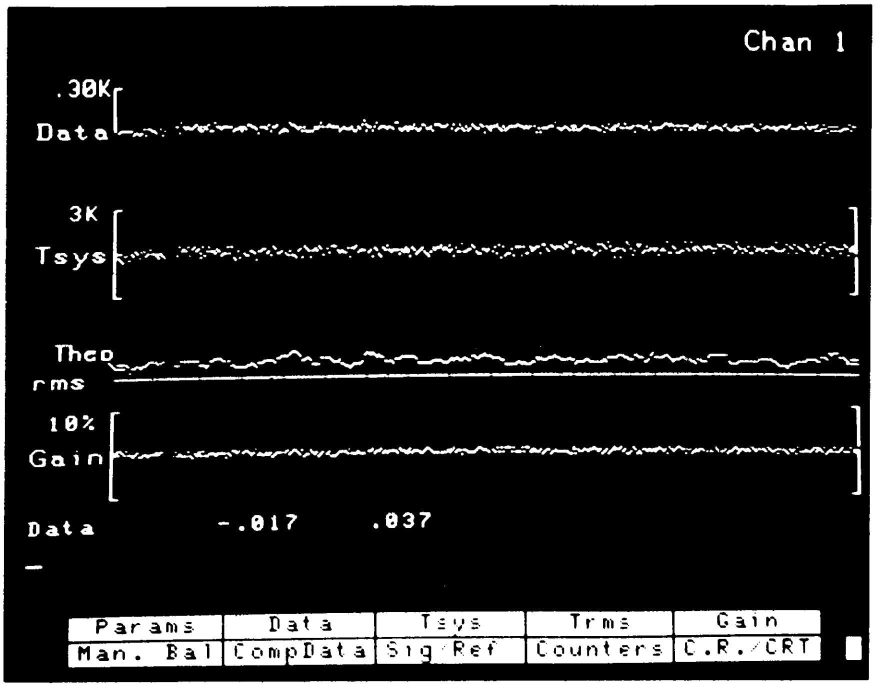

Figure 1

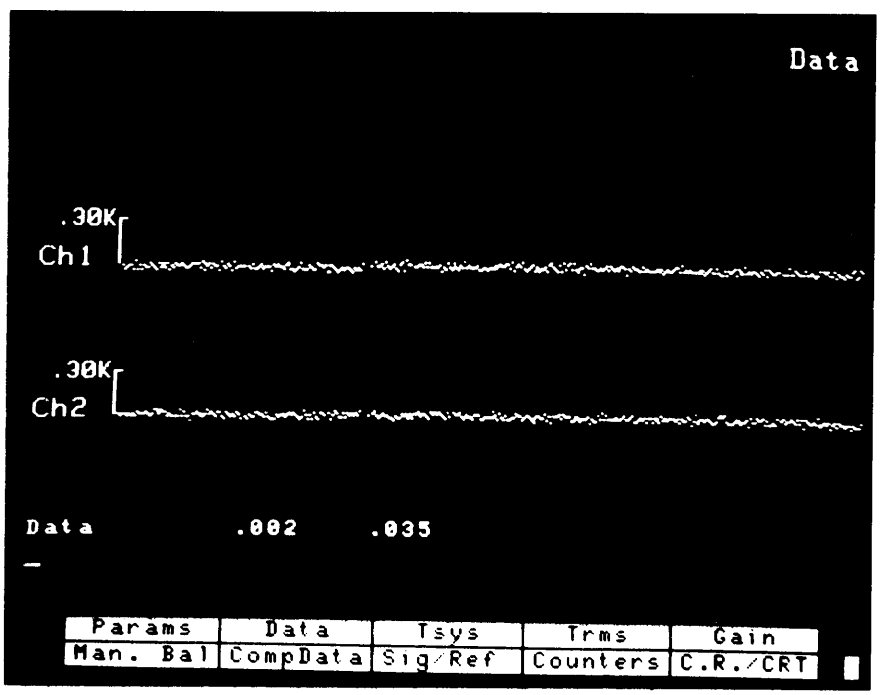

Figure 2

The all-parameter display shown in Figure 1 shows data, system temperature, a running ten-point data standard deviation, and receiver gain. The term "data" means the differential antenna temperature normally of most interest to the observer. This is either the synchronously detected output or total power less the system temperature at the beginning of the last scan depending on the receiver configuration. The system temperature is displayed relative to its first value on the graph. The absolute value may be seen by pressing the [Tsys] key. The rms graph displays the standard deviation of the last ten data points from their mean. This graph shows the ratio of the measured rms to the rms expected from the receiver system temperature, bandwidth and integration period. The horizontal mark labeled "Theo" for theoretical is the ratio of unity. The gain is the receiver gain measured from the detected cal strength relative to its strength when the [Auto Bal] or [Man. Bal] and [Gain Norm] keys were last pressed. The nominal gain value is 1.00. The first point of the graph line is offset to zero so the [Gain] key is needed to see the absolute value.

At the bottom of the CRT display are the definitions of the special function keys associated with the displays in Figures 1 and 2. These keys are active only during the idle mode. During a scan you are stuck with the last display selected. The key functions are as follows:

[Params] replaces the display with a table of the current parameters in effect for the DCR, and, if you wish, will allow you to change these parameters or set up an entirely new receiver configuration. See Figure 3, step 2.

[Data] causes the calibrated data values in Kelvins (either synchronous detector output or total power depending on the receiver configuration) for all receiver channels to be displayed below the graphs as shown in Figure 2 for a two channel receiver. New data values are displayed for each integration period.

[Tsys] causes the current system temperature for all channels to be displayed below the graphs. During the idle mode it is updated every integration period, but during a scan if the calibration noise source (cal) is not being fired the system temperature displayed will be the last one measured before the scan started.

[Trms] displays a running calculation of the standard deviation from their mean of the data values from the last ten integration periods. When this key is pressed the standard deviation expected from the system temperature, bandwidth and integration period is displayed for a few seconds before showing the measured values. The expected and measured values are labeled Trms (theo) and Trms (meas), respectively.

[Gain] causes the relative receiver gain to be displayed below the graphs. It is computed from the detected calibration noise source intensity normalized to its intensity when the [Auto Bal] key was last pressed or, if a manually balanced receiver is being used, when the [Gain Norm] key was last pressed. The nominal gain value is 1.00.

[Auto Bal] allows you to balance the synchronous detector outputs (bring their values to zero) by computing new gain modulation constants from the present signal/reference ratio or to zero the total power data output by renewing the total power offset depending on the receiver configuration. When the DCR is set up for automatic balancing it is done at the beginning of every scan, and this key need be pressed only if a new balance is required without starting a new scan. This key also serves a second function; it normalizes the computed receiver gain to its present level. The gain is not normalized at the beginning of a scan, only when this key is pressed. If the [Auto Bal] key is not defined, then one or more of the receiver channels is configured for manual balancing. (See the [Man. Bal] key description.)

[Man. Bal] initiates a prompted procedure for manually setting the gain modulation constants of the synchronous detectors (step 13). This is provided when automatic balancing of the receivers at the beginning of each scan is undesirable. In a multichannel system some of the channels may use manual balancing while the rest are automatically balanced. If all are automatically balanced the [Man. Bal] key will not appear. (See the [Auto Bal] key description.)

[CompData] displays the 16-bit integers being sent to the telescope computer. This number contains the same information as that displayed with the [Data] key, the only difference being a scale factor to get the significant digits within the range of an integer. The scale factor is explained in step 2 where the parameter table is discussed. It is 2^{15}/(computer data full scale).

[Sig/Ref] displays the gain modulation constants currently in use for a load or beam switching receiver. The gain modulation constant is the number with which detected output of the reference half of the switch cycle is multiplied to before subtracting it from the signal half. The appropriate gain modulation constant will bring the synchronously detected output to zero (balanced condition) and make it immune to receiver gain variations.

[Counters] causes the raw integrator counts to be displayed. In the scan mode only the phase zero ($\emptyset_0$) counters of the receiver channels are shown below the graphs, but in the idle mode all four phases of each receiver channel are displayed even though some of the phases may not be in use at the time.

[C.R./CRT] provides access to all of the chart recorder (C.R.) and CRT display control functions described starting with step 4.

STEP 2

DCR parameters table.

You have reached this step by pressing the [Params] key in step 1, and you will now be presented with a display similar to the one in Figure 3 including new definitions of the special function keys. To return to step 1 press the [RESUME] key.

The table in Figure 3 contains all of the parameters required for proper DCR operation. Pressing [NewParam] will allow you to change any of these parameters as described in step 3, and pressing [PrtParam] will print the table for your records.

At the top right corner of the table is the program name (U15 in this case) under which this set of parameters is stored on disk, the receiver being used (140-ft Cassegrain) and the detector mode of operation (2-phase Switching plus Total Power). To change any of these three parameters press the [New Prog] key and follow the prompted initialization procedure beginning at step 19.

[NewParam] permits you to change any of the parameters in the table in Figure 3 except the three in the top right corner. Pressing this key will send you to step 3 in this chapter.

[PrtParam] allows you to get a printed copy of the parameter table. There is not much room above the printer in the DCR rack for the paper to feed so you should check that the paper path is clear.

[RESUME] returns you to the graphic data display in step 1.

[New Prog] sends you to the DCR initialization routine which will ask a series of questions concerned with the basic DCR configuration, program name, receiver front-end, detector type, etc. The initialization routine will require about five seconds to load from disk, and its description begins at step 20.

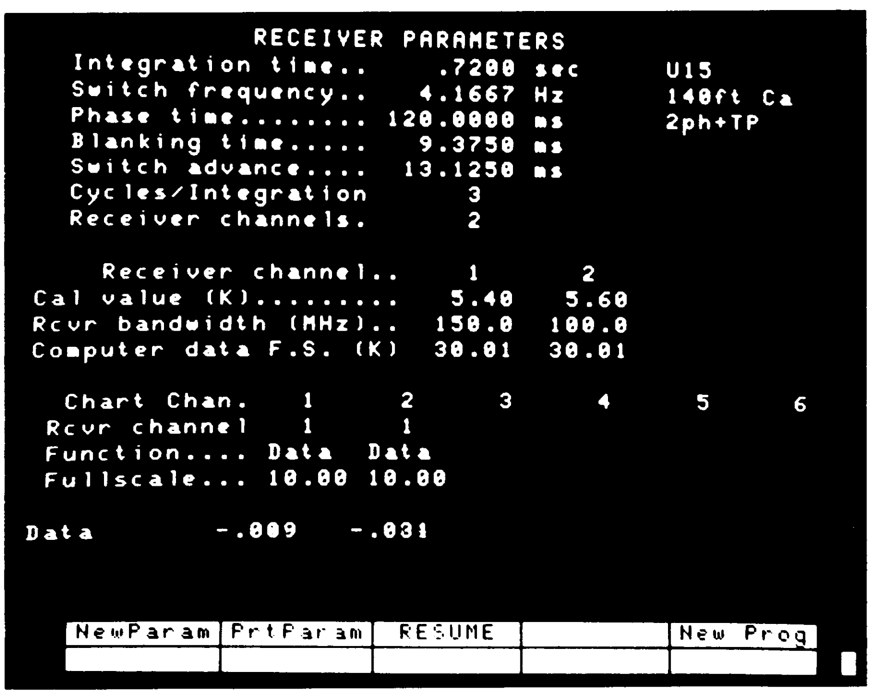

Figure 3

STEP 3

Changing parameters.

You have come to this step by pressing [NewParam] in step 2, and the display in Figure 4 will appear. A box around one

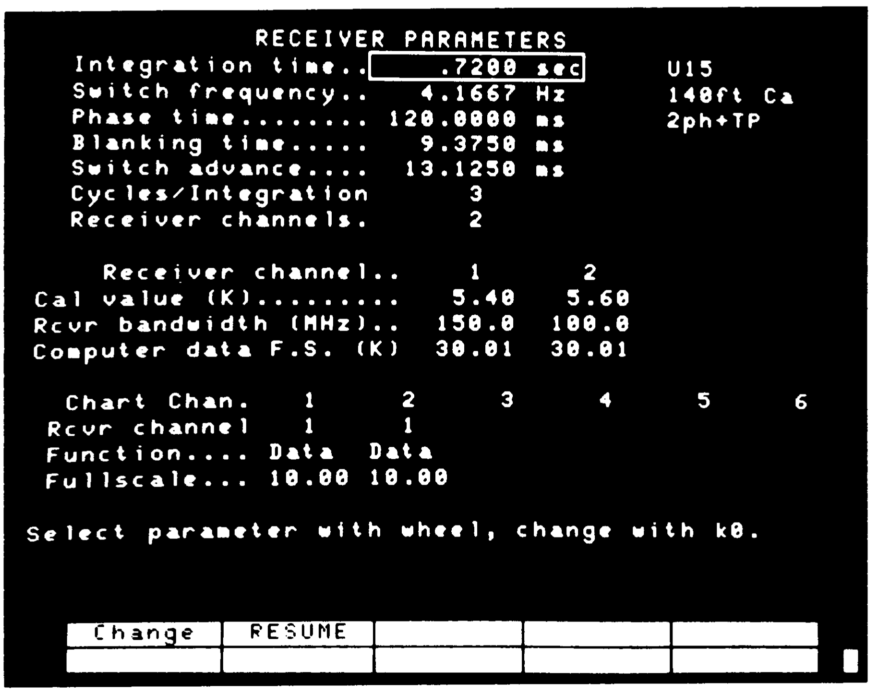

Figure 4

of the parameters in the table will now appear along with the instruction "Select parameter with wheel, change with k0." At the top left corner of the keyboard is an inset wheel whose function can be defined in the software. In this case, its rotation allows you to move the box to any of the table parameters which can then be changed by pressing the [Change] key, typing in the new value, then pressing [ENTER] near the right hand [SHIFT] key. If you forget to press the [Change] key before entering the value you will get an error message. In that case, just press [Change] and press [ENTER] again; your new value will still be on the entry line of the CRT. Each value is checked at entry time to see that it is within a reasonable range, and if not, an appropriate message is displayed. The following is a description of the parameters.

INTEGRATION TIME is the quantization time interval in sidereal time of astronomical data sent to the telescope computer. It is analogous to the time constant or an analog detector except that the digital system uses a perfect integrator where adjacent samples are statistically independent. The integration time must be an integral multiple of the phase time times the number of phases in a switch cycle (e.g., 2 phases/cycle in load switching). The calculator will compute and return the nearest possible value to the one entered if a non-integer multiple is chosen. If a particular integration time is important, a compatible phase time will have to be entered first.

SWITCH FREQUENCY is the basic switch rate (sidereal time) of the calibration noise source and the front end switch, if there is one. It is normally the reciprocal of twice the phase time. The phase time is recomputed and displayed when the switch frequency is changed, and the integration time is adjusted to be consistent with the new cycle time. Only the switch frequency or the phase time need be entered depending on which is most convenient, and the other is computed from it. The smallest quantum of phase time is 15.625 us, so the switch frequency may be slightly different from the one entered to conform to this phase time restriction. For instance, the frequency quantization interval will be 0.0032 Hz at a switch frequency of 10 Hz or 0.113 Hz at 60 Hz. The switch frequency is important for total power observations, too, since it controls the calibration switch rate in the idle mode.

PHASE TIME is the time spent on each phase of the front end or calibration switch cycle in sidereal milliseconds. It is normally half of the reciprocal of the switch frequency, and has a quantization interval of 15.625 us. Only one or the other of the phase time and switch frequency need to be entered, not both. If the phase time is changed the switch frequency will be computed and the integration time adjusted, if necessary.

BLANKING TIME is the time at the beginning of each phase period during which the digital integrators are turned off to ignore switch transients or switch transition periods. The blanking time quantization is one 64th of the phase time, and the nearest interval to the entered value will be selected.

SWITCH ADVANCE is the amount of time by which the signal to the front end switch is advanced with respect to the integrator phase time. This parameter is useful in cases where the front end switch has a lot of inertia such as with the nutating sub-reflector on the 140-ft. The blanking interval and calibration control signal remain synchronous with the integrators.

CYCLES/INTEGRATION depends on the integration and phase times and cannot be changed directly by the user. Hence, the selection box never stops at this parameter. The cycles/integration parameter refers to the scan mode. Note that during the idle mode there are often twice as many phases per cycle as during the scan mode since a calibration phase or phase set is included in the idle cycle.

RECEIVER CHANNELS is the number of IF or square law detector inputs to the DCR. This is usually equal to the number of front end channels but could be more if the signal(s) are split into more than one IF per front end channel. The DCR will ignore any inputs above the number specified.

CAL VALUE (K) is the intensity of the receiver calibration noise signal in units of the astronomical data, usually Kelvins. The cal value for each channel is available from the receiver information sheet or from the receiver engineer, and it is the standard by which many of the computed values (data, system temperature and Trms) are calibrated.

RCVR BANDWIDTH (MHz) is the receiver predetection bandwidth. The DCR does not control the bandwidth, but it needs to know what it is to compute the expected data standard deviation. This parameter has no effect on the data.

COMPUTER DATA F.S.(K) sets the largest data value which can be sent to the telescope computer without exceeding the transmitted 16-bit integer word size. If, for example, a computer data full scale of 30.01 is selected, the data are multiplied by a scale factor of $2^{15}/30.01 = 1092$ before being sent to the computer. The data will, therefore, be quantized in steps of $30.01/2^{15} = 0.0009$ K. The scale factor must be an integer which is the reason that the full scale value may not be a round number. The calculator will take the nearest acceptable value to the one entered. The computer data full scale should be set well above the largest expected radio source strength but not so high that the noise is not resolved by the integer data word. If you enter a value which may be too large for the bandwidth and integration time, you will get a message telling you what the minimum system temperature can be without undersampling the noise at the level of one quantum per standard deviation.

The last three parameter sets in the table in Figure 4 are associated with the chart recorder outputs which are driven by the calculator through D/A converters. Any of the data functions from any receiver channel may be assigned to each of the chart recorder channels. The first two channels use 12-bit D/A converters with 1/4096 resolution, and the last four use 8-bit converters with 1/256 resolution.

RECEIVER CHANNEL is the DCR input channel assigned to the particular chart recorder channel. Attempts to assign a number higher than the number of inputs in use will result in an error message. Setting this parameter to zero will cause the chart recorder output to be set to zero, and if all recorder channels above a certain number are assigned to receiver channel zero they will be ignored by the calculator saving some computation time.

FUNCTION is any of the functions displayed on the CRT shown in Figure 1 plus total power in the instance when it is computed separately from the data and system temperature. When you select one of these parameters with the box and press the [Change] key the list of available functions will appear at the bottom of the table. Abbreviations are accepted: D for Data, T for Tsys, R for rms, TP for Total Power, and G for Gain, either upper or lower case. Any spellings which contain these key letters also will be accepted.

FULLSCALE sets the chart recorder range. All but the "data function normally run with zero at the left side of the chart so their chart scale runs from zero to fullscale. "Data" is normally zero center scale, so its chart runs -1/2 full scale to +1/2 full scale. As will be explained in the chart control section, step 5, a zero offset may be applied to any of the chart functions, but the scale will remain as specified here.

STEP 4

Chart recorder or CRT display control selection.

You have arrived at this step by pressing the [C.R./CRT] key in step 1, and you will be presented with the display shown in Figure 5. You can now select control of the chart recorder

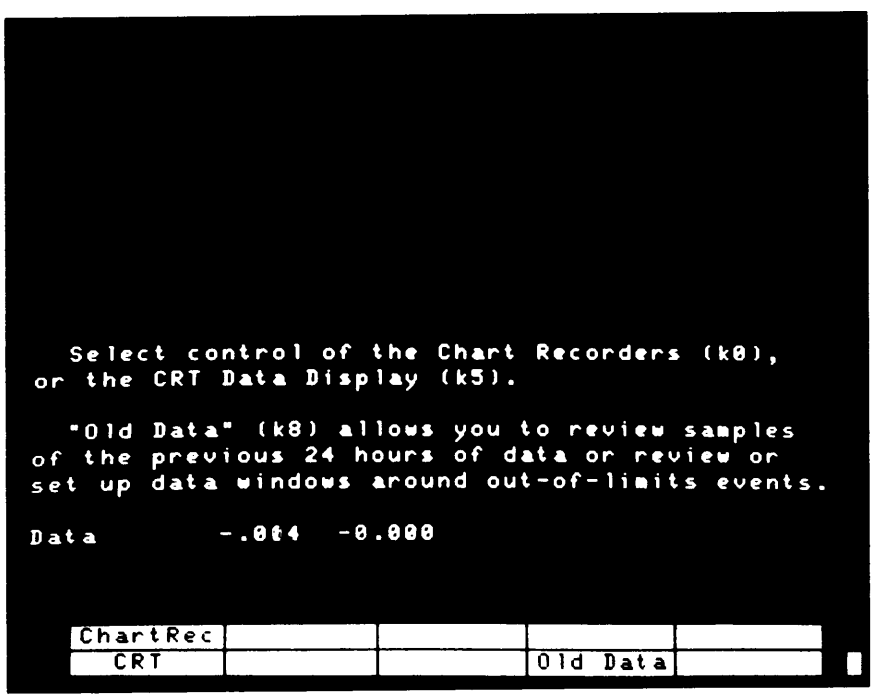

Figure 5

functions or the CRT display by pressing the proper special function key. The [Old Data] key provides access to disk-stored samples of data from the past 24 hours and windows of data surrounding out-of-limits conditions usually specified by the receiver engineer. (See step 14.) This old data is primarily for receiver diagnostics and is probably of little interest to the observer. The occurrence of a start scan signal when examining old data would be awkward.

[ChartRec] establishes control of the chart recorder scales and pen positions through step 5.

[CRT] provides control of the CRT graph scales and function displays beginning with step 6.

[Old Data] gives access to data samples stored on disk primarily for receiver diagnostics through the procedure beginning at step 15.

STEP 5

Chart recorder scale and zero control.

This step is entered through the [C.R./CRT] and [ChartRec] keys in steps 1 and 4, respectively. You will now see the display in Figure 6 which explains most of the chart recorder control functions. Some elaboration on these controls is given below.

[ChartSel] is a stepping key to select the chart recorder channel to be affected by the other keys or the keyboard wheel. The selected recorder is shown at the bottom right corner of the display after this key is pressed.

[NoOffset] removes any zero offset which may have been introduced by the other keys or the keyboard wheel. This key is useful when you want to re-establish the absolute zero on the chart.

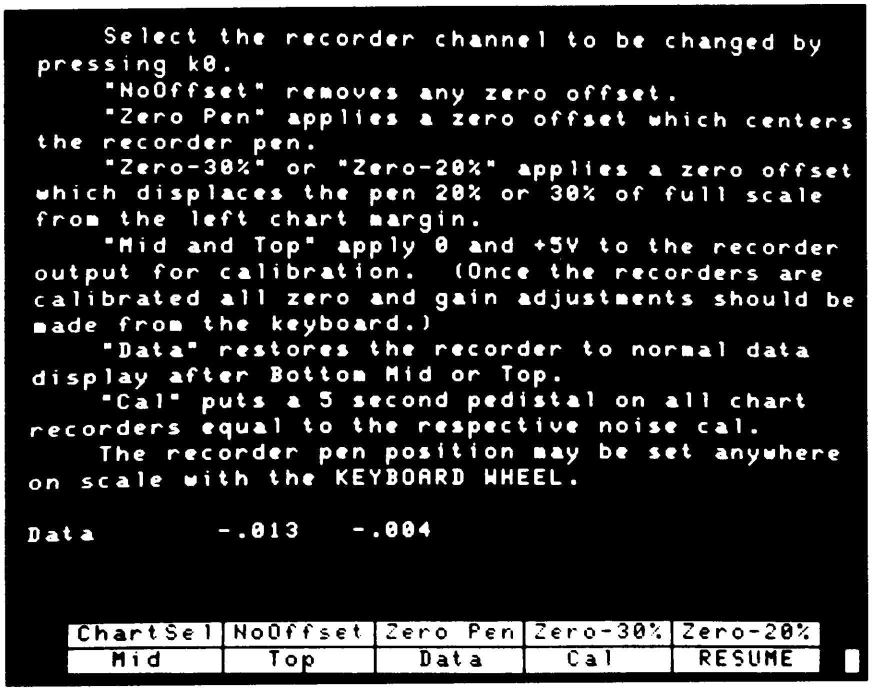

Figure 6

[Zero Pen] brings the pen to center scale by setting the zero offset exactly equal to the displacement of the pen from center at the time this key is pushed. It is a quick way to bring a pen on scale, particularly with a very sensitive scale or a large zero offset.

[Zero-20%] is the same as the [Zero Pen] key except that the pen is set 30% of full scale from the left margin instead of the center (50%). This and the [Zero - 30%] keys may be useful for offsetting two pens on a dual channel recorder.

[Zero-30%] is the same as the [Zero Pen] key except that the pen is set 20% of full scale from the left margin instead of center (50%).

[Mid] sets the chart recorder voltage to mid-scale (zero volts output from the D/A) for the purpose of setting the chart recorder pen to center scale with its zero control knob. This is different from the [Zero Pen] key in that data are no longer sent to the chart recorder until the [Data] or [RESUME] key is pressed.

[Top] sets the chart recorder voltage to its maximum positive value (4.96 V) for the purpose of setting the chart recorder pen to top scale with its gain control knob. Note that once the zero and gain controls on the chart recorder are set they should not be touched during normal operation since the D/A's output is limited to +-5 volts. Gain and zero adjustments should be made from the keyboard.

[Data] restores the chart recorder to normal operation after using the [Mid] or [Top] key.

[Cal] puts a calibration signal on all of the chart recorder outputs for five seconds. The Data, T_{sys} and Total Power functions are incremented by an amount equal to the calibration noise source for the associated channels. The noise source is not actually turned on. The Rms function is set to the value expected from the receiver bandwidth, system temperature and integration time (Trms (theo)). The Gain function is set to unity for the five second interval.

[RESUME] returns you to the normal CRT data display (step 1) and restores normal operation of the chart recorders if they were left in the "Mid" or "Top" condition.

KEYBOARD WHEEL provides continuous control of the chart recorder pen position in very much the same fashion as the zero control of the recorder itself without the restriction of misaligning the chart recorder scale with the +-5 V range limits of the recorder output. Use this wheel instead of the control on the recorder. The wheel only works in this capacity when the display in Figure 6 is on the screen. If the chart recorder is hard to see when you are at the keyboard, you could monitor the chart recorder output on the large meter below the calculator by setting the switch to the appropriate chart recorder channel. This meter runs +-10 V, zero center, so it uses only the center half of the scale in this function.

STEP 6

CRT display format and scale control.

This step is accessed by pressing the [C.R./CRT] key in step 1 and the [CRT] key in step 4. The display will look like Figure 7. From this point you can select one of the two graphic displays in Figures 1 and 2 with the [All Param] and [All Data] keys. If you select the all-parameter display you will be asked for the channel number, or, if this display is already selected, you may change channels with the bottom row of keys. To change the vertical scale on any of the CRT graphs press [Ch Scale] an proceed to step 7 or 9.

[All Data] selects the display format shown in Figure 2 for the number of receivers in use. The new display will appear as soon as this key is pressed, and you will be back to step 1. If you also want to change scales you will have to press the [C.R./CRT] and [CRT] keys again.

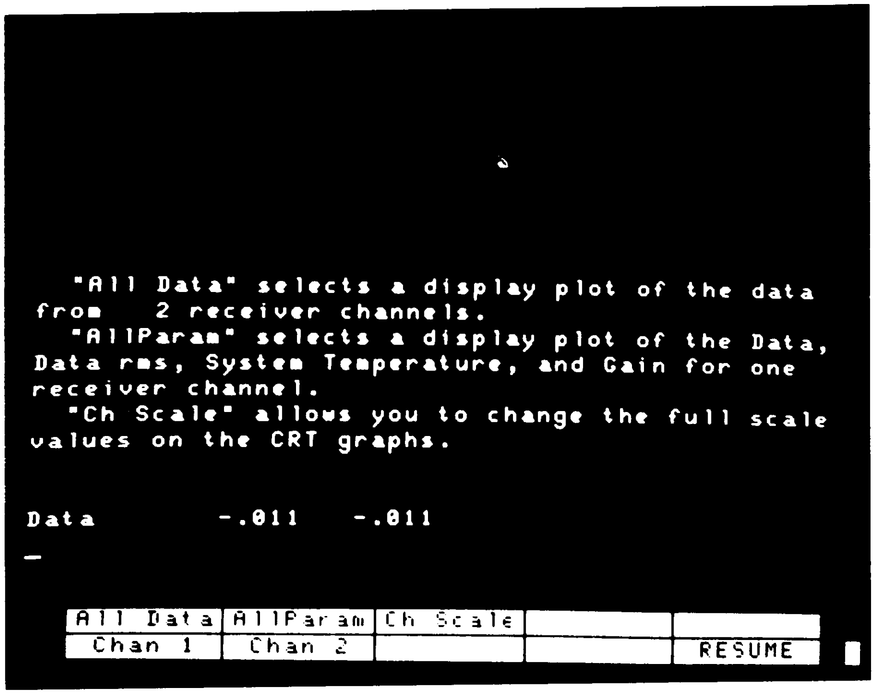

Figure 7

[AllParam] selects the display format shown in Figure 1. After this key is pressed you will be asked "Which receiver channel?" to which you should respond with one of the [Chan 1], [Chan 2] ... keys. Pressing the channel selection will return you to step 1.

[Ch Scale] initiates a vertical scale selection procedure for the display selected above. Go to step 7 or 9, depending on whether the all-data or all-parameters display is in effect, respectively. Keep in mind when setting scales that the Data, T_{sys} and Gain graphs are plotted with a zero offset equal to the value of the first point of a 360-point plot scale, so a full scale much smaller than the absolute data values is often desirable.

[Chan X] is one of up to four keys for choosing the channel to be displayed in the all-parameters selection. After one of these keys is pressed you will return to the graphic display and step 1.

[RESUME] returns you to one of the displays in step 1 with the current selections and scales.

STEP 7

Changing "All Data" CRT scales.

You are at this point because of pressing the [Ch Scale] key while the all-data display is in effect. Now choose the channel for which the scale is to be changed as requested in Figure 8 using [Chan X] keys. The [RESUME] key gets you back to the display without further scale changes. After pressing a channel key you will be at step 8.

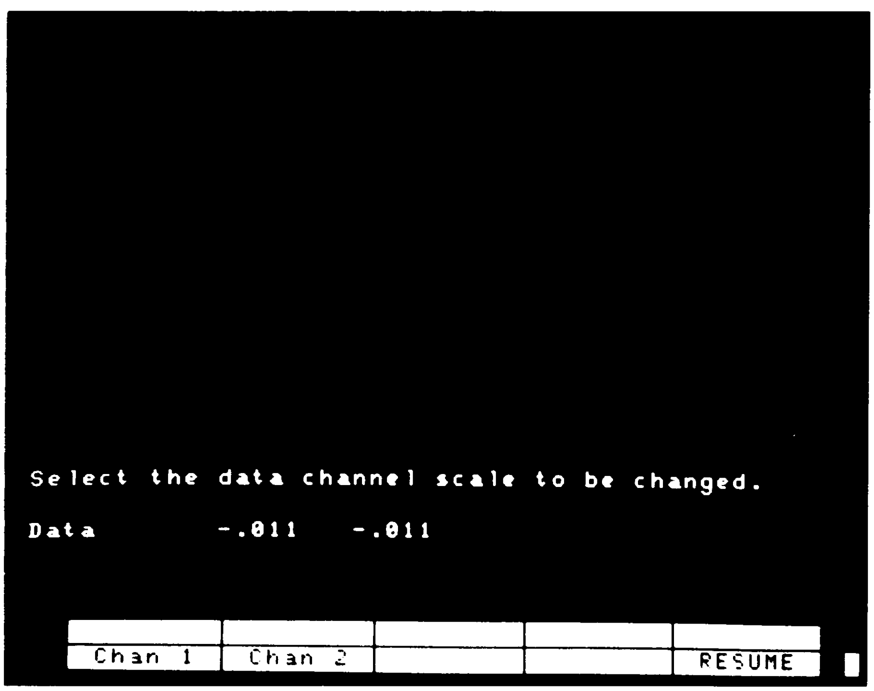

Figure 8

STEP 8

Step 7 continued.

This step is reached from the channel selection in step 7. You are now presented with a choice of full scale values as shown in Figure 9. These values refer to the intensity

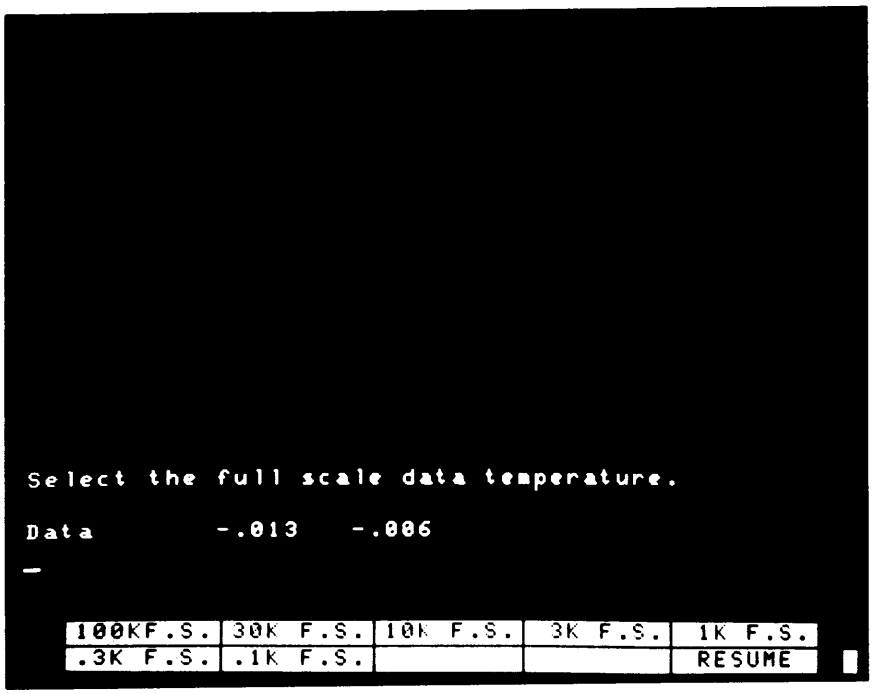

Figure 9

corresponding to the vertical bar on the left end of each graph in Figure 2. With fewer than four channels the display range will actually be considerably larger than this. Once a selection is made you will be returned to step 7, Figure 8. The [RESUME] key serves its normal function of returning you to the graphic display in Figure 2, step 1.

STEP 9

Changing "AllParam" CRT scales.

The [Ch Scale] and [Chan X] keys in step 6 with the all-parameters display selected have sent you to this step. You now have the choice presented in Figure 10 of changing the scale of one of three display functions. The rms graph has a fixed scale not under user control. The [Data] key leads to the selection in step 10, [Tsys] to step 11 and [Gain] to step 12. The [RESUME] key restores the display in Figure 1 and sends you back to step 1.

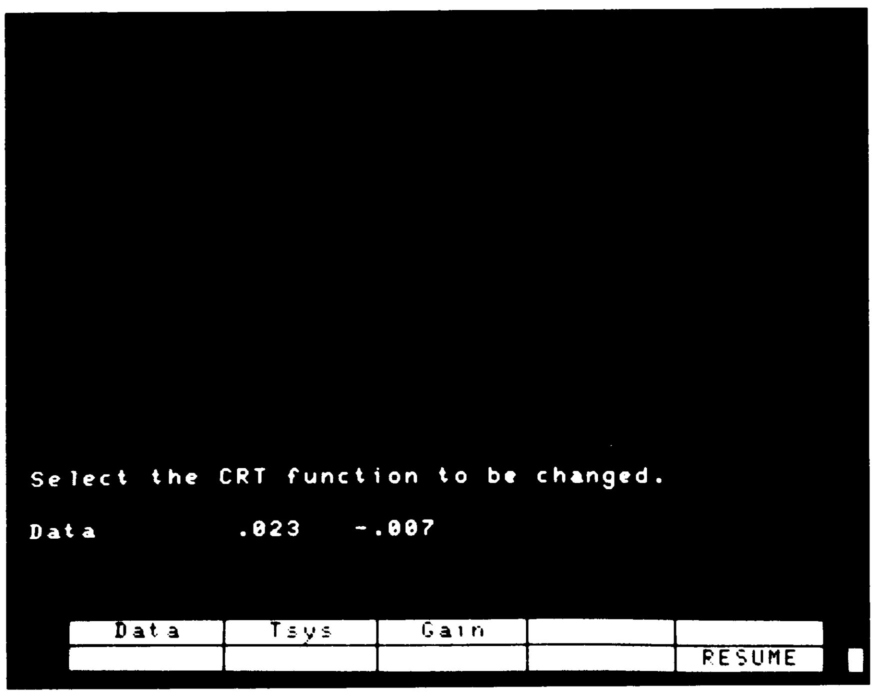

Figure 10

STEP 10

Changing CRT Data scale.

This step from the [Data] key in step 9 is identical to step 8 and the display is like the one in Figure 9 except that you will be returned to step 9, Figure 10, after making a selection, and the [RESUME] key will restore the Figure 1 display.

STEP 11

Changing CRT Tsys scale.

You are here from the [T_{sys}] key in step 9, and you will see the display in Figure 11. The full scale values refer to half of the length of the vertical bar at the left end of the graph in Figure 1. After making a selection you will be returned to step 9, Figure 10. [RESUME] restores the display in Figure 1 with the current scales.

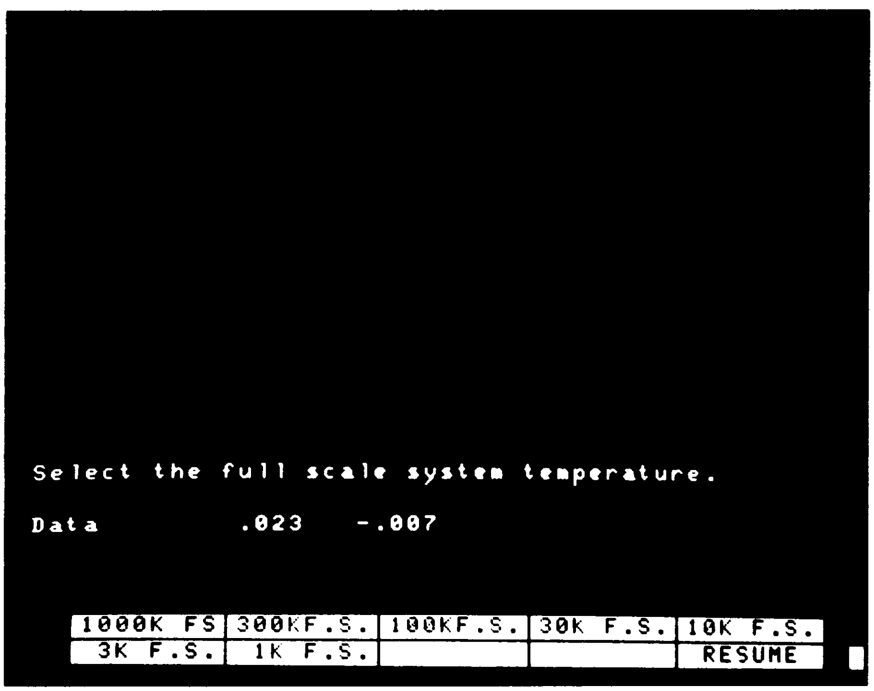

Figure 11

STEP 12

Changing CRT Gain scale.

This point is reached through the [Gain] key in step 9, and the Figure 12 display will now appear. The full scale value refers to half of the length of the vertical bar at the left end of the Gain graph in Figure 1. When you have made your selection you will be returned to step 9, Figure 10. The [RESUME] key sends you directly to step 1 and restores the display in Figure 1 with the current scale values.

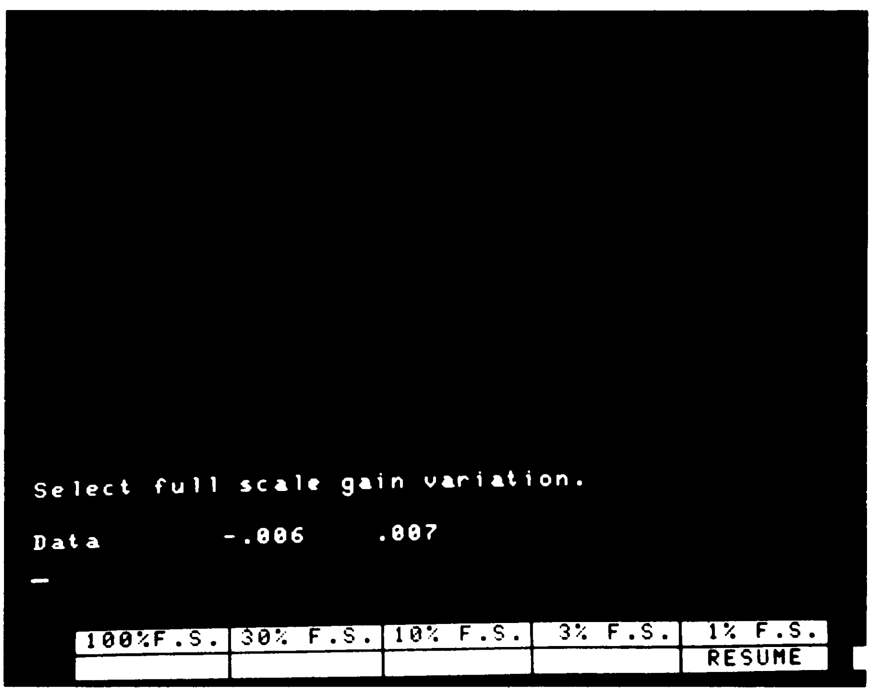

Figure 12

STEP 13

Manual balancing and gain normalization.

This step is reached by pressing the [Man. Bal] key in step 1. The display in Figure 13 will now appear on the CRT

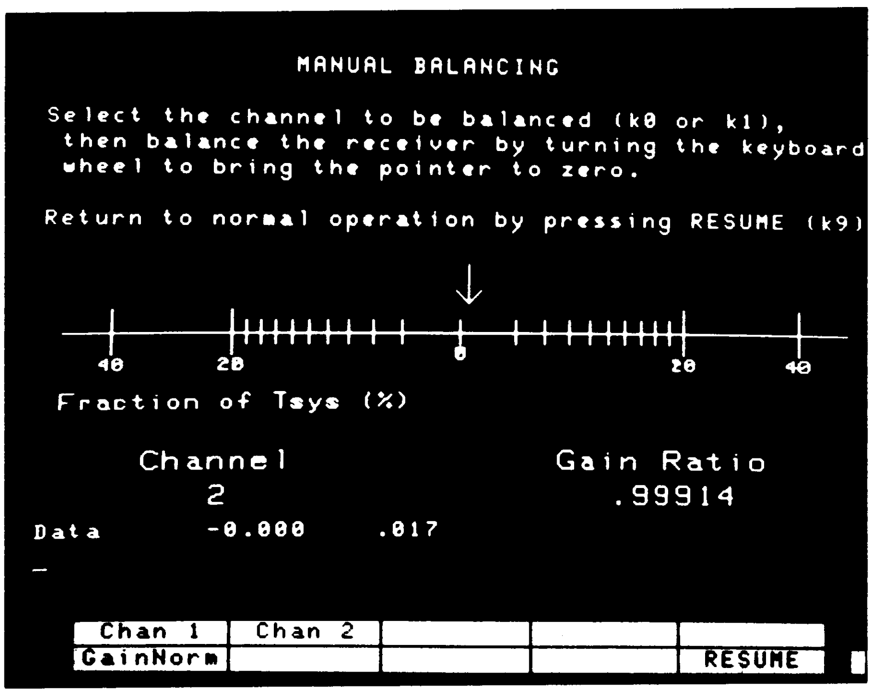

Figure 13

with a flickering arrow above the horizontal scale which shows the fractional imbalance of the channel selected. The DCR uses the arithmetic equivalent of receiver gain modulation in the load and beam switching modes to produce equal levels on the signal and reference phases of the front end switch cycle. The integrated detector output from the reference half of the switch cycle is multiplied by a gain ratio before being subtracted from the signal half, and if this difference, called the synchronously detected output, is zero it is immune to any receiver gain changes. The current gain ratio is shown in the display and can be changed by rotating the wheel at the top left corner of the keyboard. And the wheel is rotated the arrow will move along the scale to show the offset from balance. Both the display and the wheel control are nonlinear with the arrow and gain ratio moving rapidly near either end of the scale and smoothly transitioning into a vernier action near center scale with expanded display resolution. The numerical gain ratio display is not changed until the wheel has been stopped for a second or so. You will see the arrow jumping around a bit even when you are not moving the wheel because the receiver output is updated every integration period. Gain ratios for each of the receiver channels may be changed by pressing the corresponding special function key. The [Gain Norm] key allows you to normalize the computed receiver gain to its current value (set it to unity) to which all subsequent gain values are referenced. This does not affect the astronomical data in any way. The gain is primarily a receiver monitor function. The [RESUME] key sends you back to the normal display in step 1.

STEP 14

Old data review and limits control.

You have reached this step by pressing the [Old Data] key in step 4. Two forms of past data samples are now available for inspection by pressing either the [Samp Rev] or [LimitRev] key in Figure 14.

During normal operation of the DCR, data from one integration period every minute are stored in memory as a kind of log of system operation. These data include the "Data", "Tsys", "rms" and "Gain" values plus the time of sample. The memory arrays are large enough to hold 24 hours of data. Every two hours the last 120 samples are stored on one of 12 disk records so that if the DCR power fails most of this data can be recalled. Under normal telescope operation a disk record is written only immediately after receipt of an "end scan" signal so that a scan is not interrupted or delayed. To access and display this memory or disk data press the [Samp Rev] key and go to step 15.

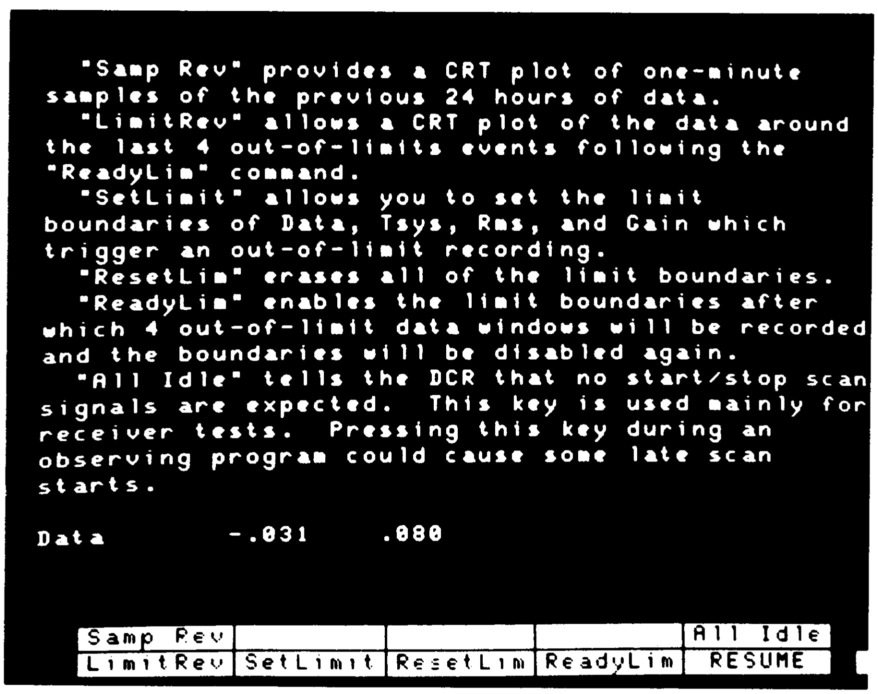

Figure 14

In addition to the one-minute samples up to four windows of 360 contiguous data samples may be stored on disk upon detection of an out-of-limits condition. Upper and lower limits on any of the four data functions may be set by pressing the [SetLimit] key and following step 17. When all of the functions are within the specified limits, the first half of the 360-point array is continuously refreshed, and when an out-of-limits condition is detected the second half is filled so that the window is centered on the triggering event. As with the sample data recording, a record is normally written only after an "end scan" signal is received. After the limits are specified the [Ready Lim] key must be pressed to activate the limits after which a maximum of four records are written, and after the fourth record the limits are deactivated until the [Ready Lim] is pressed again. The limits can be effectively erased with the [Reset Lim] key, and the requirement of writing only at an "end scan" can be overridden with the [All Idle] key. To display any of the four windows press the [LimitRev] key and go to step 16.

STEP 15

Reviewing 24 hours of one-minute samples of old data.

This step is accessed through the [Old Data] and [Samp Rev] keys in steps 4 and 14. You will now be presented with a display similar to the one in Figure 15. You can choose one of the display formats shown in Figures 16 and 17 with the [AllParam] and [All Data] keys. These are very similar to the ones in

Figures 1 and 2 with the addition of a vertical cursor and associated time and data values at the bottom of the display. Since only 6 of the 24 hours of data can be displayed at a time the last 6 hours are initially plotted, and the older data are accessed by moving the cursor to the left with the KEYBOARD WHEEL. As the cursor moves left older data begin appearing at the right hand end of the display in reverse fashion to the repeating displays of Figures 1 and 2. By moving the cursor over a particular feature its relative time of occurrence can be read at the lower left, and the numerical data values read to the right of the time.

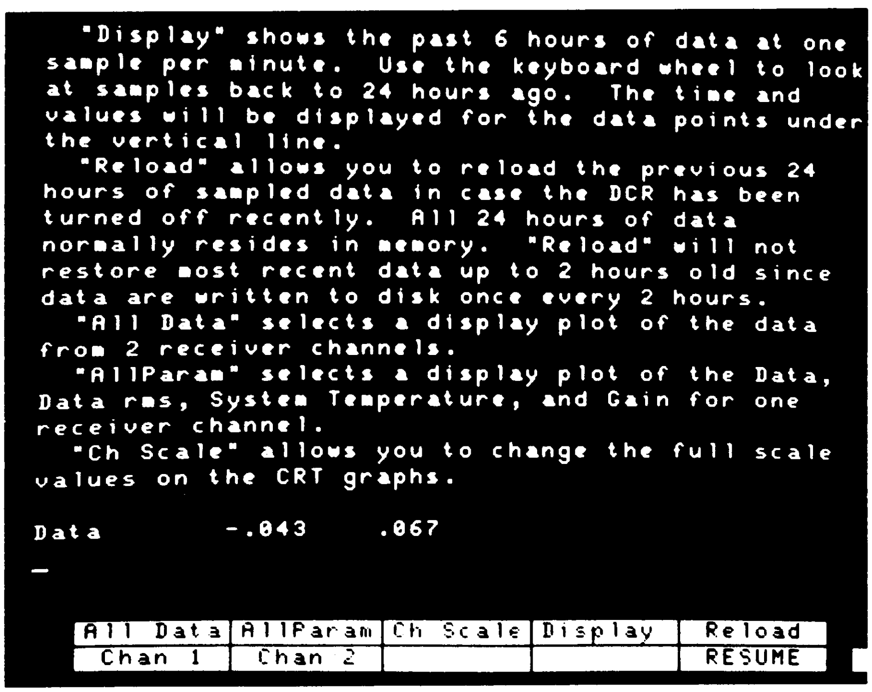

Figure 15

The purposes of the special function keys are as follows:

[All Data] selects the display in Figure 17 and plots the last six hours of data. The time and numerical data display will appear when the vertical cursor is moved with the keyboard wheel.

[AllParam] selects the display in Figure 16. Before the graphs are plotted the channel number to be displayed will be requested, and a selection is made with the [Chan 1], [Chan 2] ... keys. After the channel number is chosen the last six hours of data are plotted.

[Ch Scale] allows you to change the vertical plot scales in the way described in steps 8 or 10 with the exception that control is returned to this step when the scales have been adjusted.

[Display] initializes the chosen display and plots the last six hours of data in memory. This key is necessary after [Reload] but not after [All Data] or [AllParam] is pressed.

[Reload] reads the 24 hours of sampled data on disk into the calculator memory. This will be necessary if the calculator has been turned off for some reason, but if the recent data are still in memory this key should not be used since as much as two hours of the most recent samples will not yet be on disk and will be lost with [Reload].

[Chan X] selects the channel to be displayed with the [AllParam] functions.

[RESUME] restores the current data display, Figure 1 or 2, and returns you to the key definitions of step 15, Figure 14.

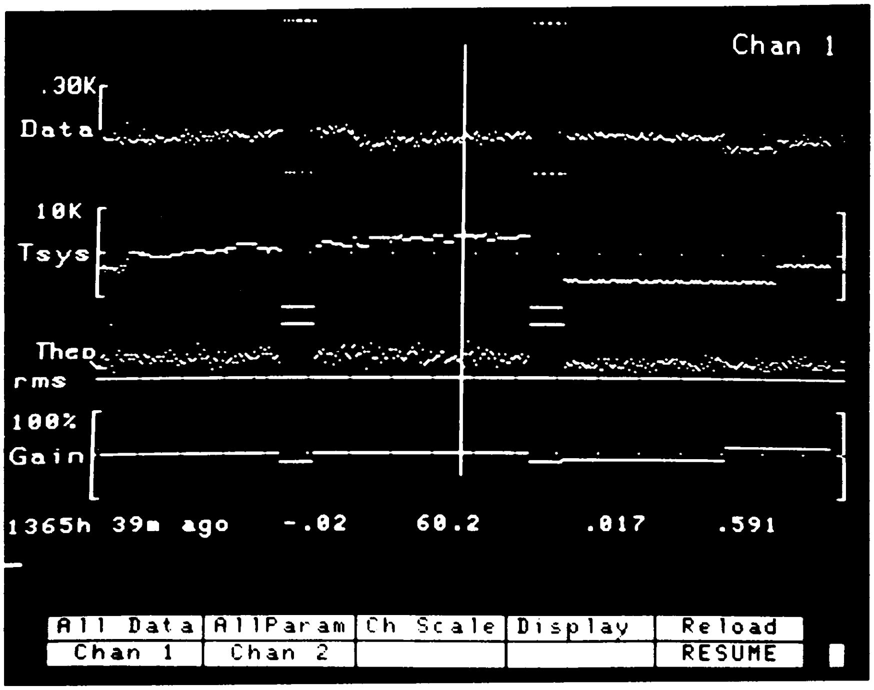

Figure 16

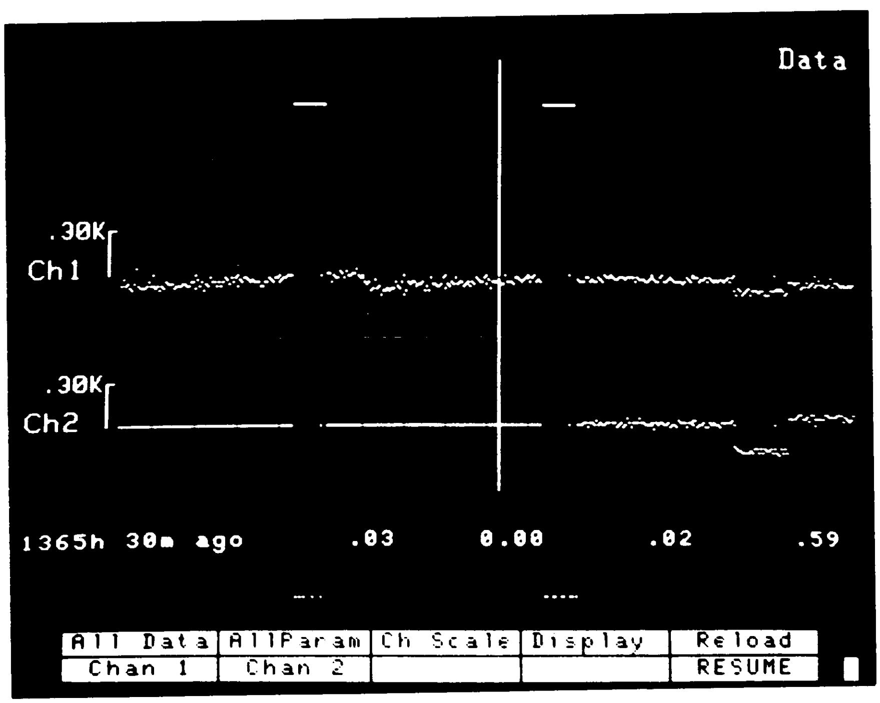

Figure 17

STEP 16

Reviewing "out-of-limits" data windows.

This step is reached through the [LimitRev] key in step 14. The display in Figure 18 will now appear which asks you to select which of the last four recorded out-of-limits windows is to be displayed. (See Figure 19.) Since data from only one channel are recorded in each window the all-parameter display will be used. The "First Point" numbers below the graphs give the values of the first data points which are used as zero offsets for each plot beginning with "Data" on the left and ending with "Gain" on the right. The [Ch Scale] key allows you to adjust the vertical display scales as described in step 9, and the [RESUME] key returns you to the key definitions of step 14 with the current data plot of either Figure 1 or 2. The time at the top of the plot is associated with the center point in the

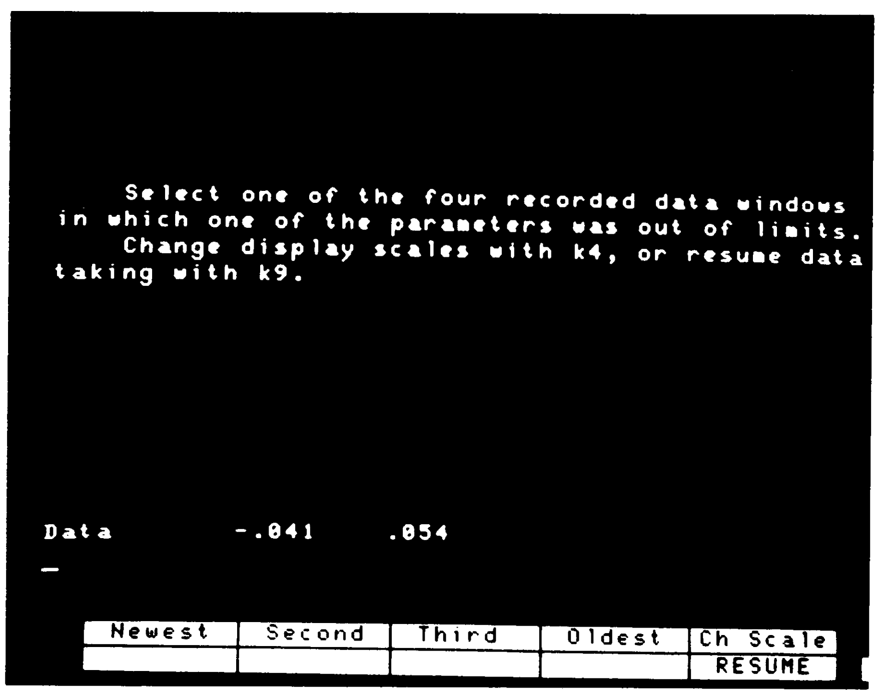

Figure 18

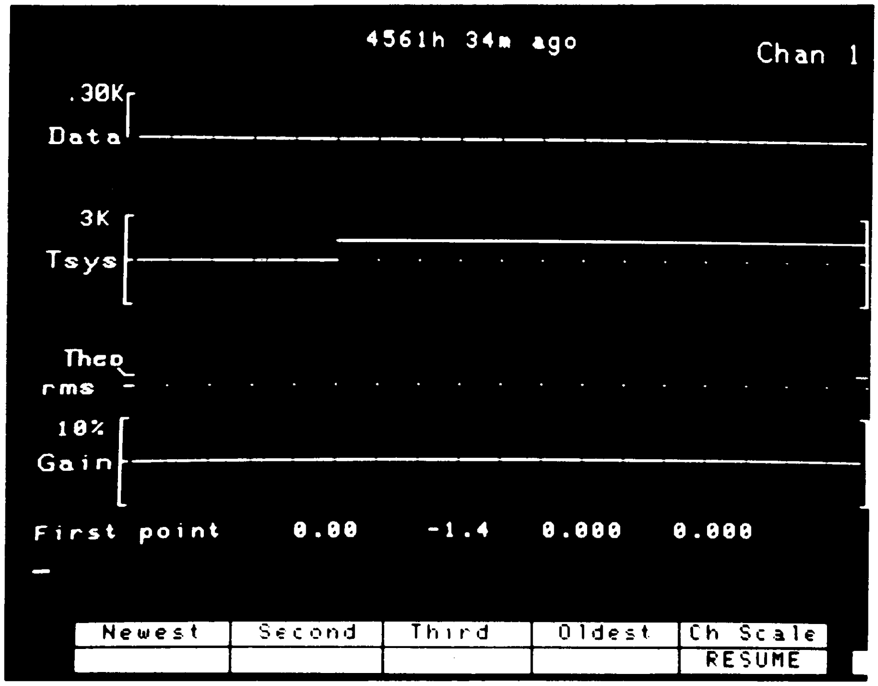

Figure 19

STEP 17

Setting limit checking boundaries.

This step is reached by pressing the [SetLimit] key in step 14. You may now set the boundaries to be used by the out-of-limits checking roiutine in recording a data window described in steps 14 and 16. The limits are set by moving the box in the display shown in Figure 20 to the appropriate place and pressing the [Change] key in much the same way as receiver parameters are changed. Initially the limits are set to the largest positive or negative numerical value possible in the calculator (+-1.7 E308), and a very high limit value is indicated by X's in Figure 20. When a new upper limit is entered a check is made to ensure

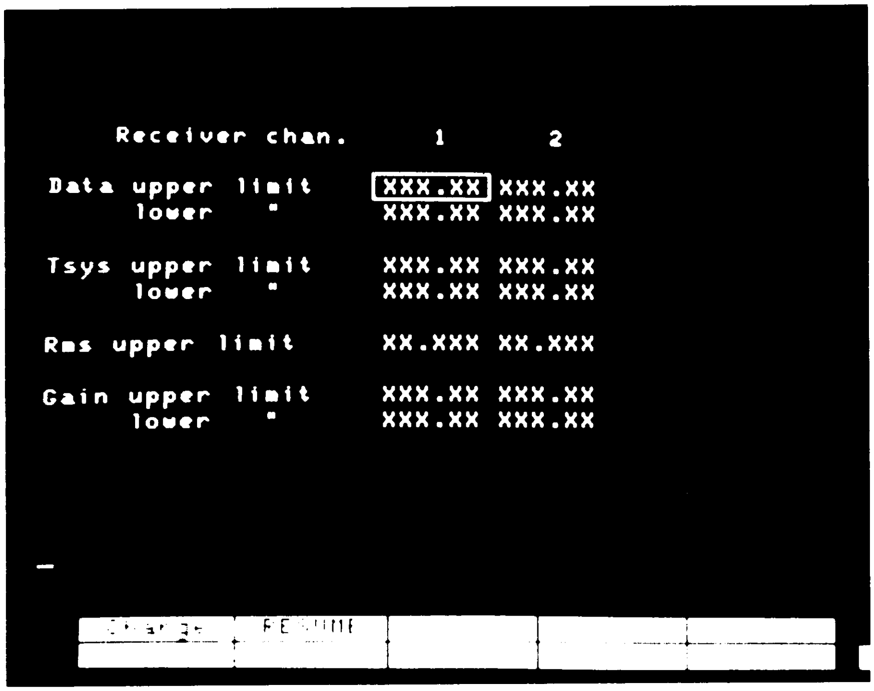

Figure 20

that it is more positive than the corresponding lower limit and vice versa when a lower limit is entered. If, for instance, both the new upper and lower limits want to be more negative than the current lower limit, change the lower limit first. Only an upper limit is specified for the "Rms" since a lower limit did not seem useful. Pressing the [RESUME] key will produce the display in Figure 21 to alert you to enable the limit checking if desired. Press [RESUME] again if you do not want to enable the limit checking at this time or press [ReadyLim] then [RESUME] if you do. Of course, all of the other key functions in Figure 21 are available before pressing [RESUME] for the second time as described in step 14.

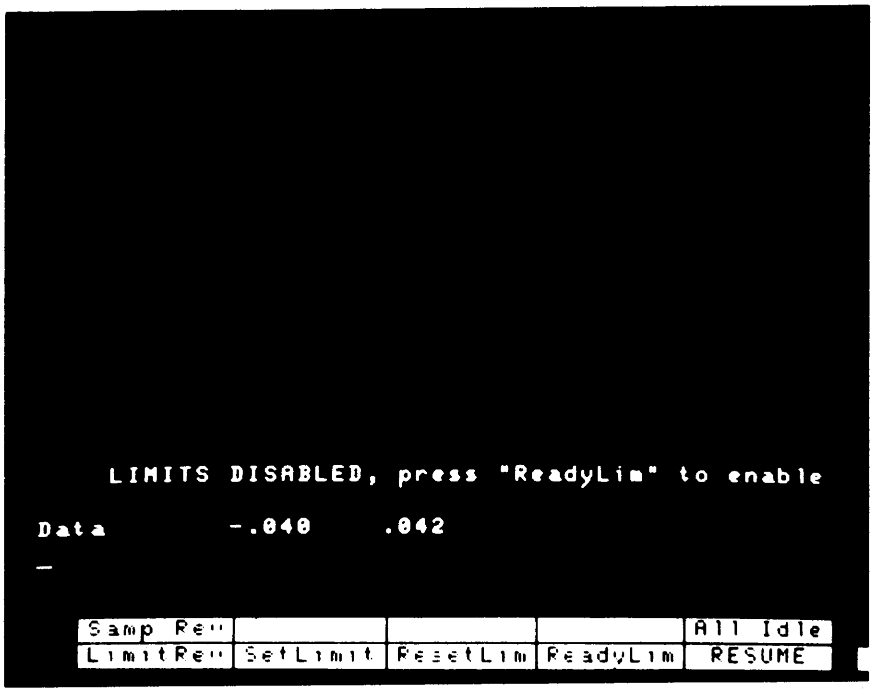
LIMITS DISABLED, press "ReadyLim" to enable
Data -.040 .042
Samp Rev
All Idle
LimitRev
SetLimit
ResetLim
ReadyLim
RESUME

Figure 21

Setting up a New Program or Reloading an Old One

If you have just fired up the DCR or you want to change the receiver configuration you will have to answer a few questions and enter a few parameters before filling out the parameter table in step 2. If the calculator has just been turned on start with step 18, otherwise skip to step 19.

STEP 18

Setting the internal HP9826 clock.

The HP9826 has an internal clock which is used in the DCR for logging of sampled data stored on the internal disk. This clock must be set with the correct time when the calculator is first turned on. None of the DCR timing functions are derived from the calculator clock so its accuracy is not terribly important. When the 9826 is turned on the query in Figure 22 will appear.

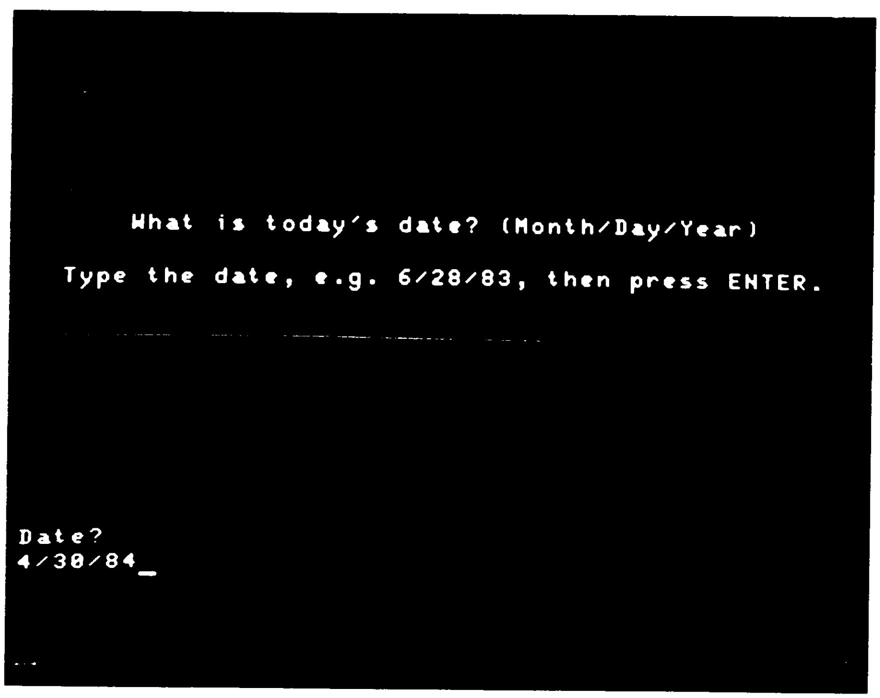

Figure 22

Answer by typing the date in the order specified using slashes or spaces between the month, day, and year, then press the [ENTER] key. Next answer the question in Figure 23.

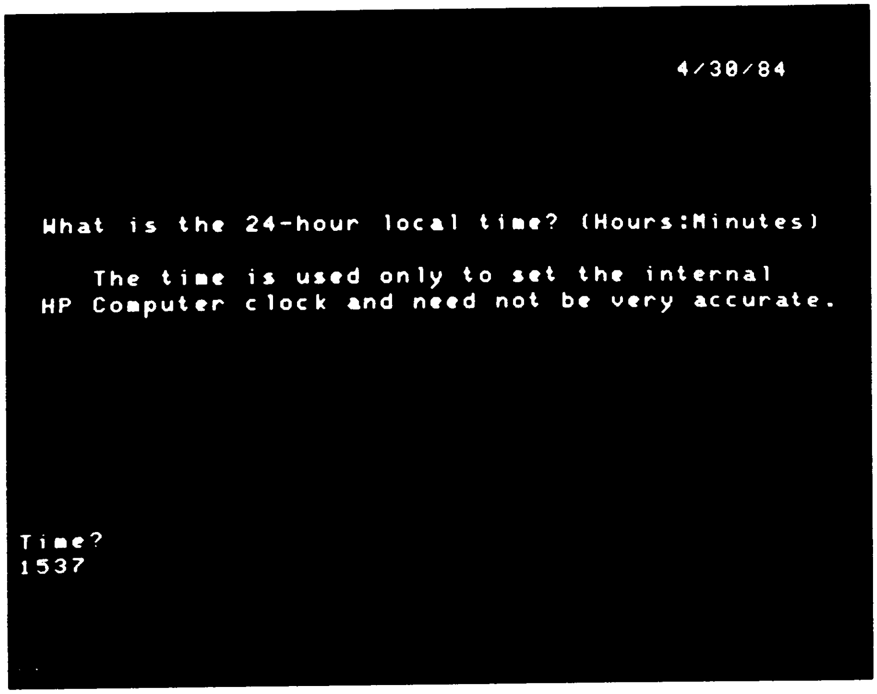

Figure 23

Here the hours and minutes need not necessarily be separated as long as the minutes are specified with two digits, e.g., 1404. Press [ENTER] after typing the time, and this will send you to step 19.

STEP 19

New or old program selection.

You now are presented with the choice of creating a new receiver setup or reloading an old one as the result of either setting the internal clock after power-up or pressing [New Prog] in step 2 of the main program. Press one of the special function keys which are defined at the bottom of the display in Figure 24

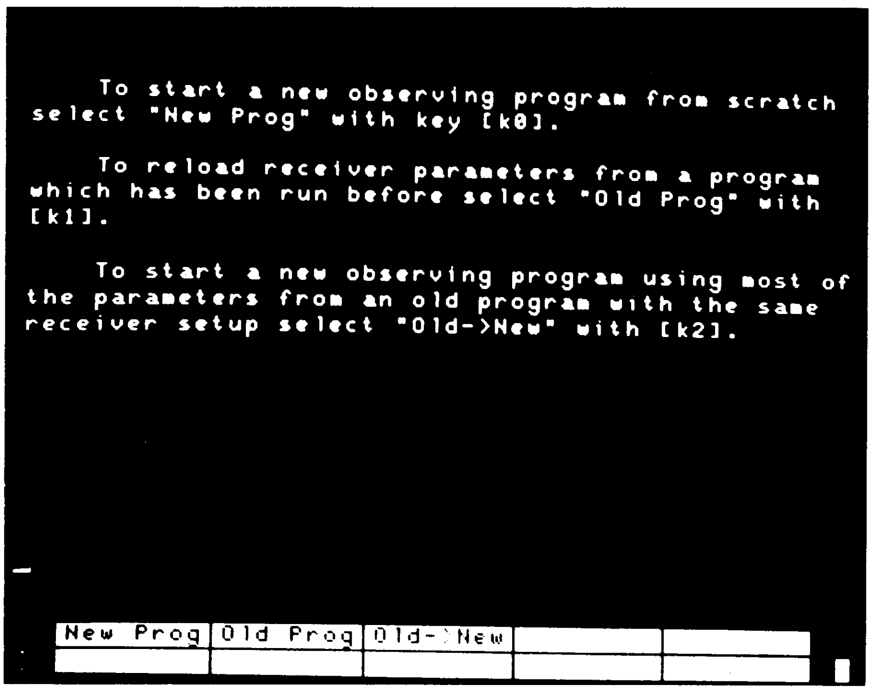

Figure 24

and explained in the display text. There are 40 records on disk which contain old setups under user-specified program names, so if you have used the DCR in recent months chances are good that your old setup is still there. The oldest of the 40 setups is overwritten by a new setup, and if an old program is recalled it becomes the newest one of the 40 without overwriting an old one. If you press [Old Prog] go to step 20, otherwise go to step 21.

STEP 20

Reloading an old program setup.

By selecting [Old Prog] in step 19 the display in Figure 25 will appear. If you are uncertain of the name of the old

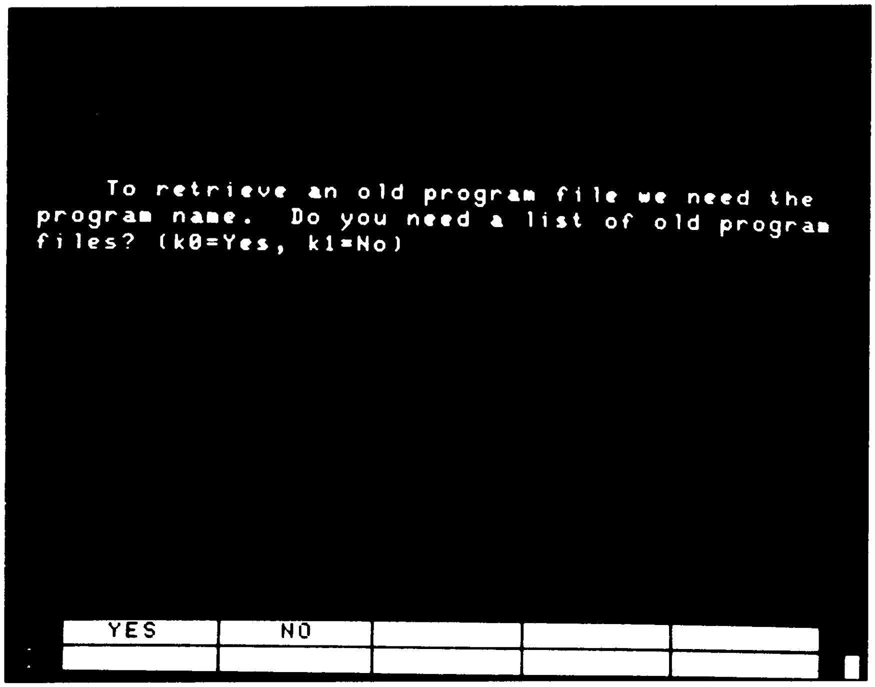

Figure 25

setup that you intend to recall, a list of all of the stored setups can be produced by answering [YES] to the question in Figure 25 and a display similar to Figure 26 will appear. Since the names of all 40 records cannot fit on the screen the older ones can be scrolled into view with the wheel at the top left of the keyboard. Pressing the [NO] key will produce the prompt in Figure 27. With the display of either Figure 26 or Figure 27 type the old program name and press [ENTER]. If the old record is found it will be loaded; the main data taking program will be loaded and you will be at step 1. If a record with

the specified program name cannot be found, step 20 w:
repeated.

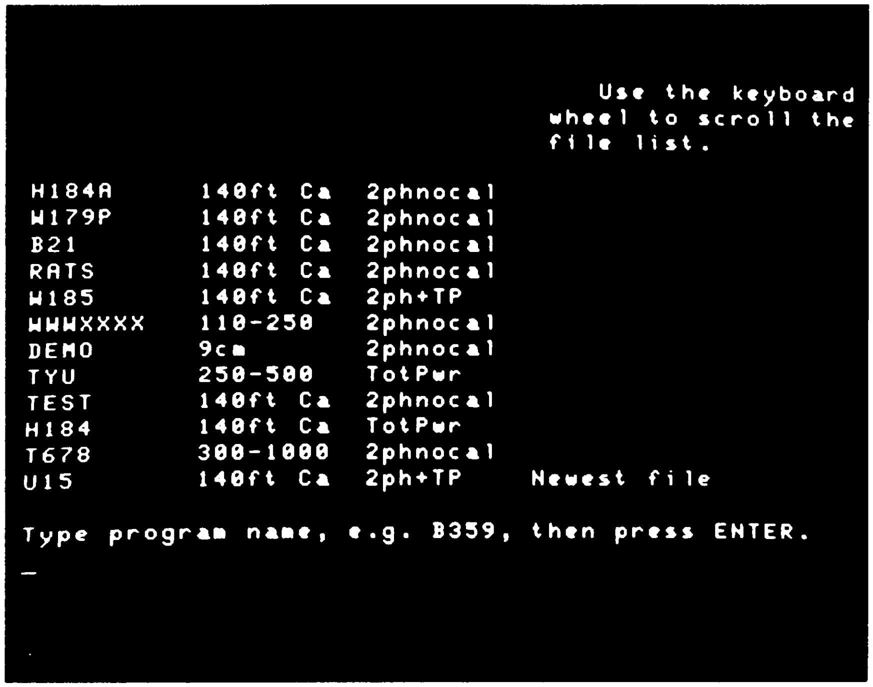

Figure 26

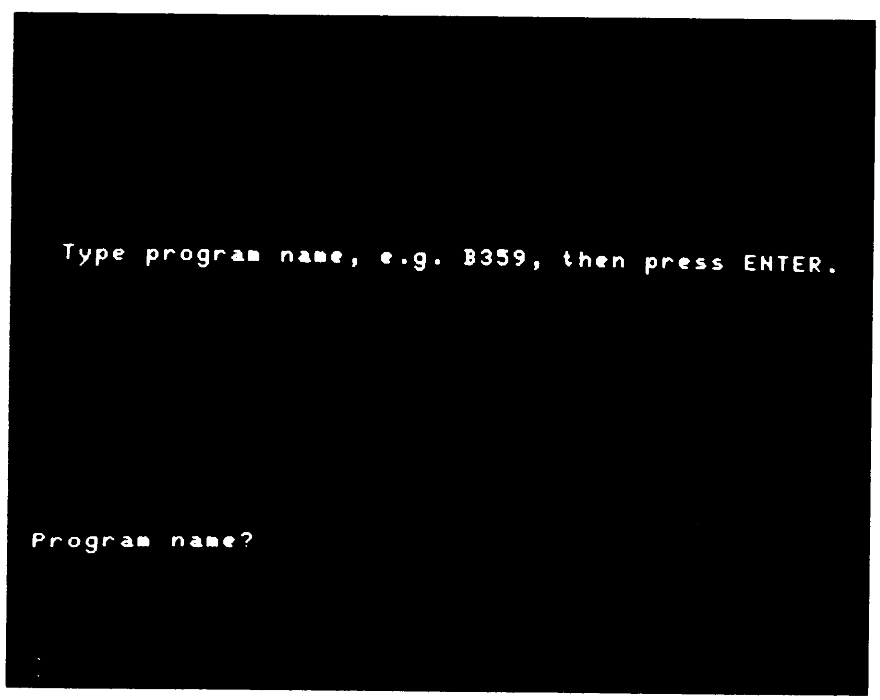

Figure 27

STEP 21

Setting up a new program.

A new program setup needs a short name by which it can be called to reload it in the future without going through the whole setup procedure again. Probably the most unique and related name to use is the observing program name on the telescope schedule, e.g., B359, although any name of eight letters or fewer will do as long as it has not been used before. To the prompt in Figure 28 type your program name, press [ENTER] and go to step 22.

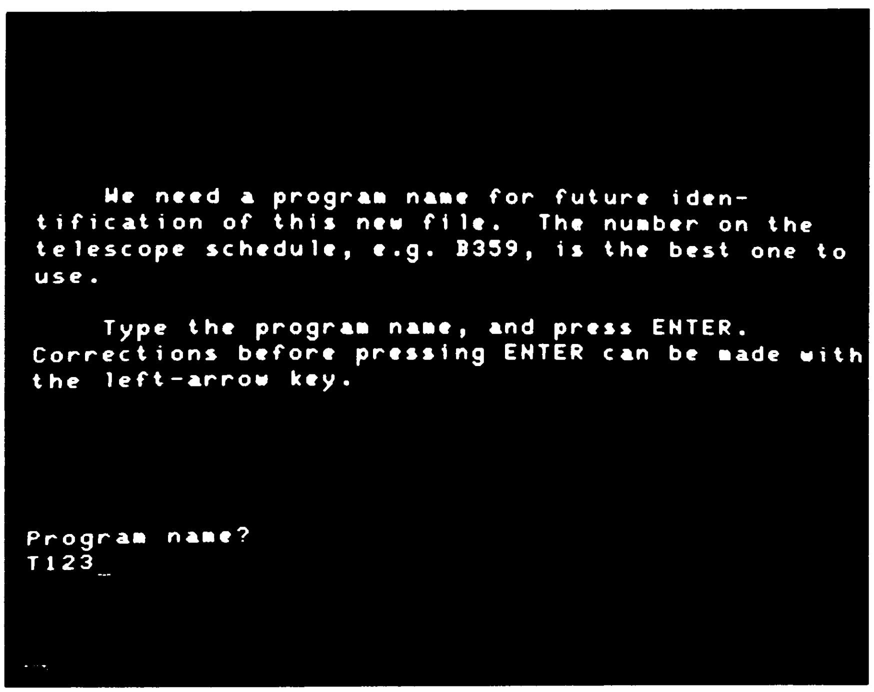

Figure 28

STEP 22

Receiver selection.

Now designate the receiver to be used with the DCR by picking one from the list in Figure 29 and entering its corresponding number. If the one you are using is not on the list use "other", and type an eight or fewer letter designation when requested.

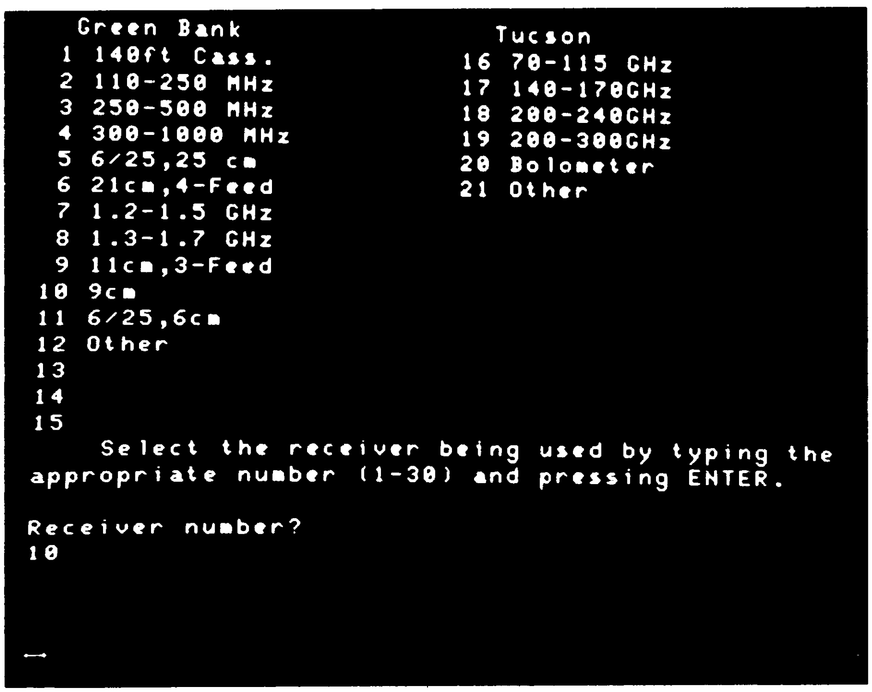

Figure 29

If a setup using the same receiver and detector scheme is on record some of the following questions may not have to be asked. In the off chance that the DCR program assumes something about your receiver that you cannot change later in the program you can circumvent most assumptions by using "Other" and a receiver name never used before. Proceed to step <u>23</u>.

STEP 23

Detection scheme selection.

Three detector modes are presently available in the DCR software plus one combined mode. Any one of these can be chosen by responding to the next display shown in Figure 30. "Load

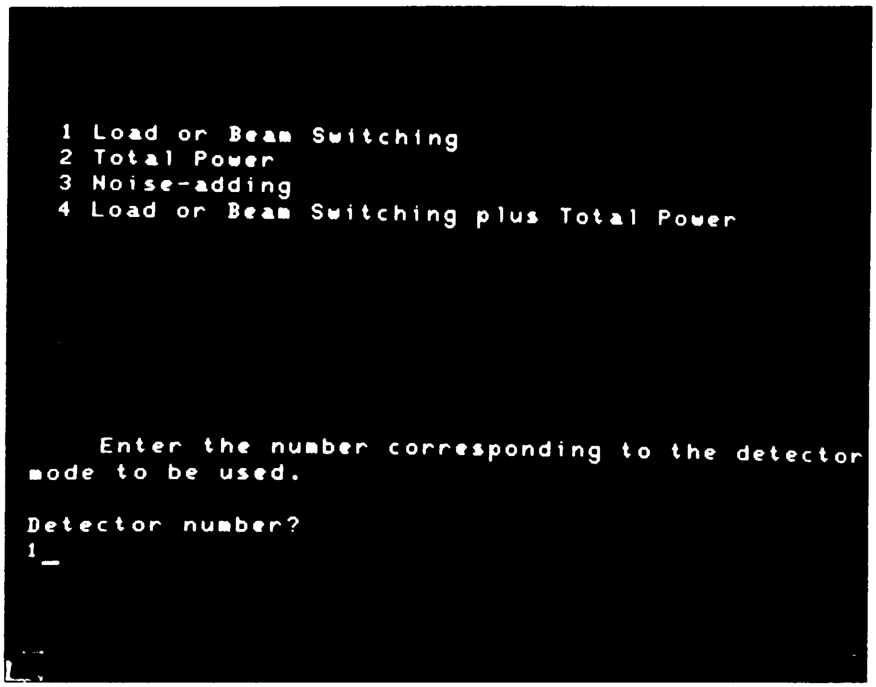

Figure 30

or Beam Switching" uses two integrator phases, signal and reference, in the scan mode, and in the idle mode it uses four phases: signal plus cal, reference, signal, and reference. "Total Power" uses one phase during the scan mode and two during idle, signal plus cal and signal. By its nature "Noise Adding" uses two phases in both scan and idle modes, signal plus a very large cal and signal. The "Load or Beam Switching plus Total Power" detector mode puts the synchronously detected data in the lowest numbered channels sent to the telescope computer (channels 1 through the number of receiver channels, N) and the total power data in channels N+1 to 2N. The total power has no DC offset removed so it is nearly equivalent to system temperature. Temperature scales are continuously updated during the idle mode, and the last available calibration is used for the following scan. Once a detector has been selected the calculator will search the program setups on file to see if this system has been used before; if so you will skip to step 26, otherwise continue to step 24.

STEP 24

Calibration mode selection.

The DCR needs to know whether the receiver front end has a calibration noise source (cal) which can be controlled by the DCR. Most receivers do, but if yours does not you will have to set the temperature scale manually. Answer the query in Figure 31 by pressing the [YES] or [NO] key. The [Restart]

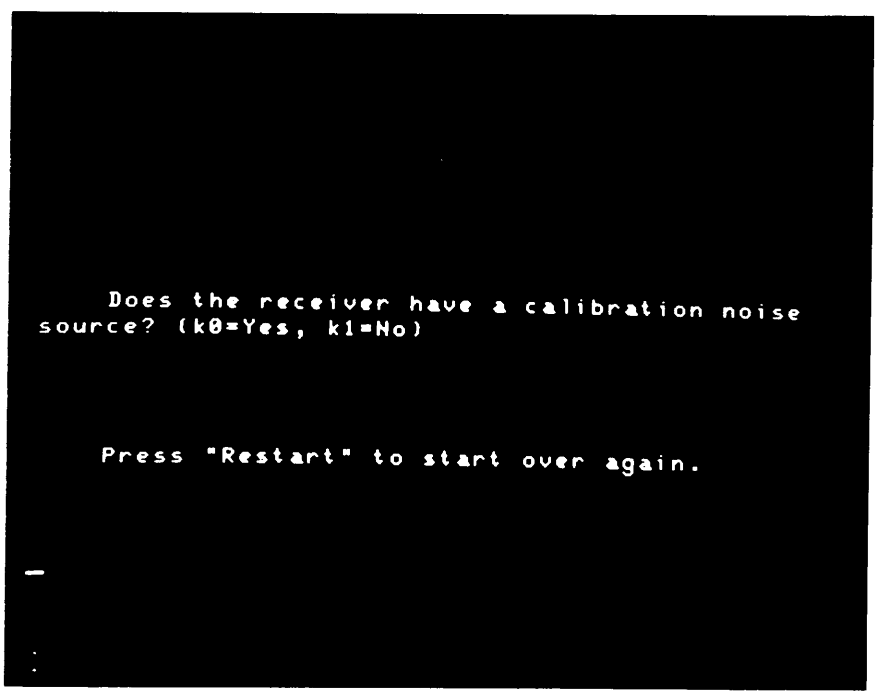

Figure 31

key will get you back to step 19 in case you have made a mistake before this point. (Note: This step may not be implemented in your version of the DCR.)

STEP 25

Entry of number of receiver channels.

Now enter the number of receiver inputs to the DCR which are to be used in response to the display in Figure 32. This number can be changed after the data taking program is loaded.

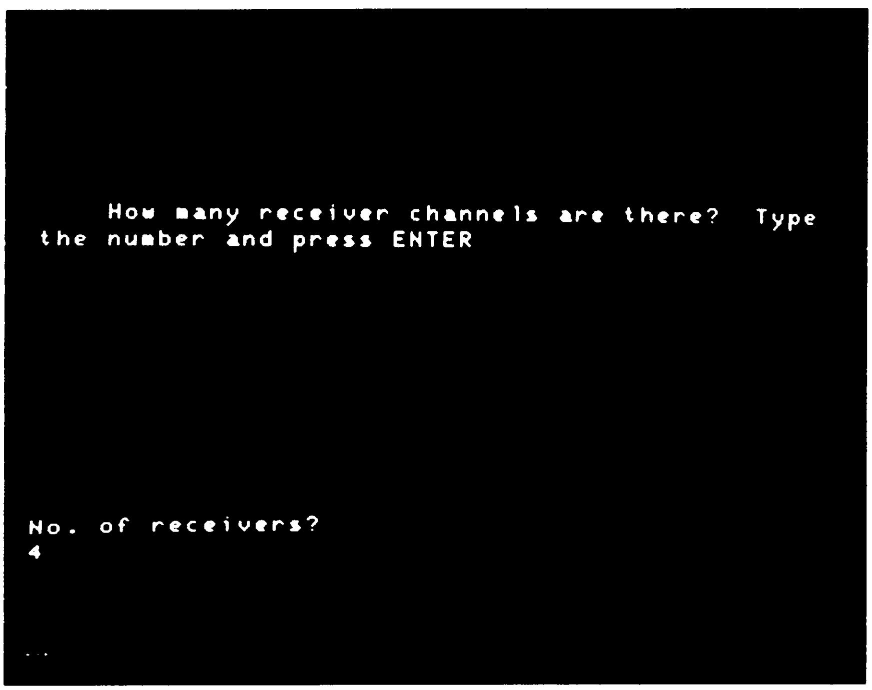

Figure 32

STEP 26

Setting total power computer scale factor for "Load or Beam Switching plus Total Power".

If you have not selected "Load or Beam Switching plus Total Power" detection scheme, option 4 in step 23, skip to step 27. Since there is no DC offset removed from the total power data in this detector configuration, different scales are usually required for the switched and total power data channels sent to the telescope computer. The switched data scale will be set later, but the total power scale must be set by answering the question in Figure 33. A separate value must be entered for each receiver channel. The system temperature that you put in here only affects the total power computer data scale factor and has no effect on anything else in the DCR, so you may use a value other than the actual system temperature if there is some advantage to doing so.

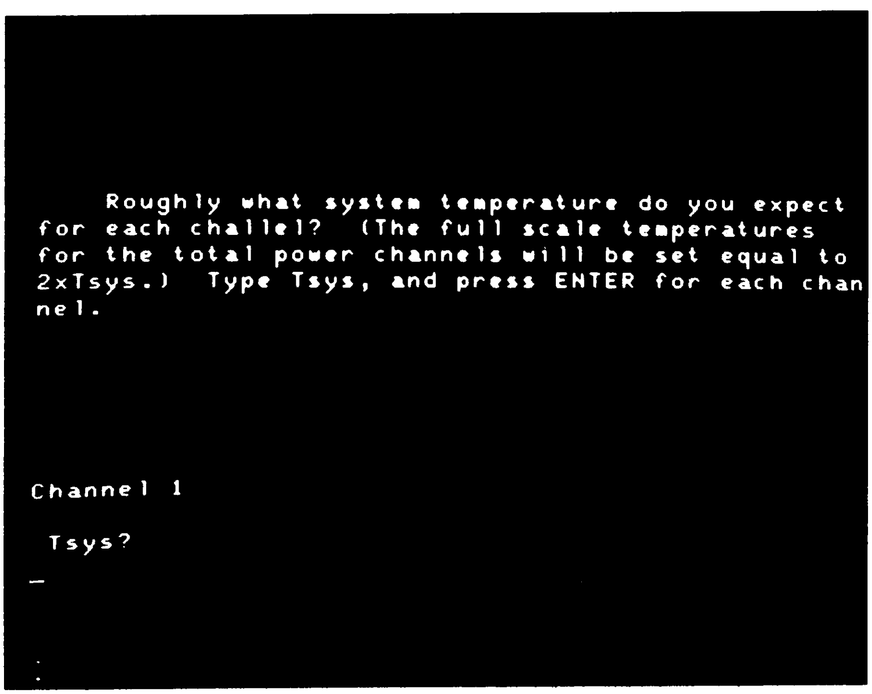

Figure 33

STEP 27

Automatic or manual detector balance selection.

At this point you are asked how you want the detector offsets treated at the beginning of each scan. The synchronous detector in a load or beam switched receiver is normally balanced for zero output in the absence of a radio source by adjusting the relative receiver gain in the reference half of the switch cycle. This relative gain can be computed automatically at the beginning of each scan or it can be set manually and kept at a constant value for all scans. Manual setting is used when receiver gain immunity is not as important as atmospheric noise cancellation or having a known and constant signal to reference gain ratio. Select [AUTO] or [MANUAL] with one of the keys shown in Figure 34. You can have some of the receiver channels balanced manually and others balanced automatically by pressing [MANUAL] and specifying the channels in the next step. If you choose [AUTO] skip to step 29.

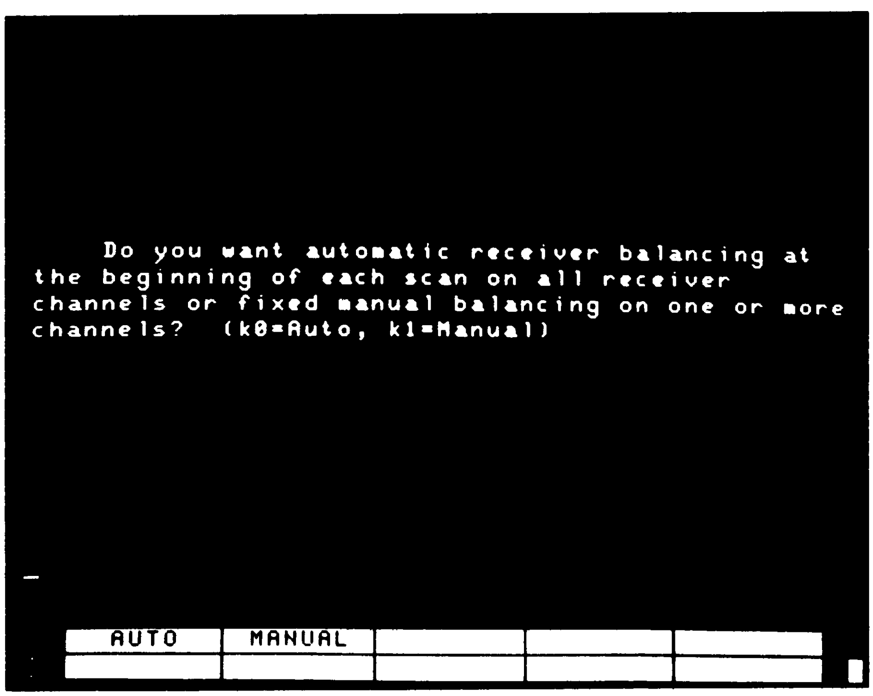

Figure 34

STEP 28

Manually balanced channel selection.

You have selected manual balancing in step <u>27</u> producing the display in Figure 35. Now type the channel numbers to be manually balanced and hit [ENTER]. All unspecified channels will be automatically balanced. Typing A or ALL will request that all channels be manually balanced.

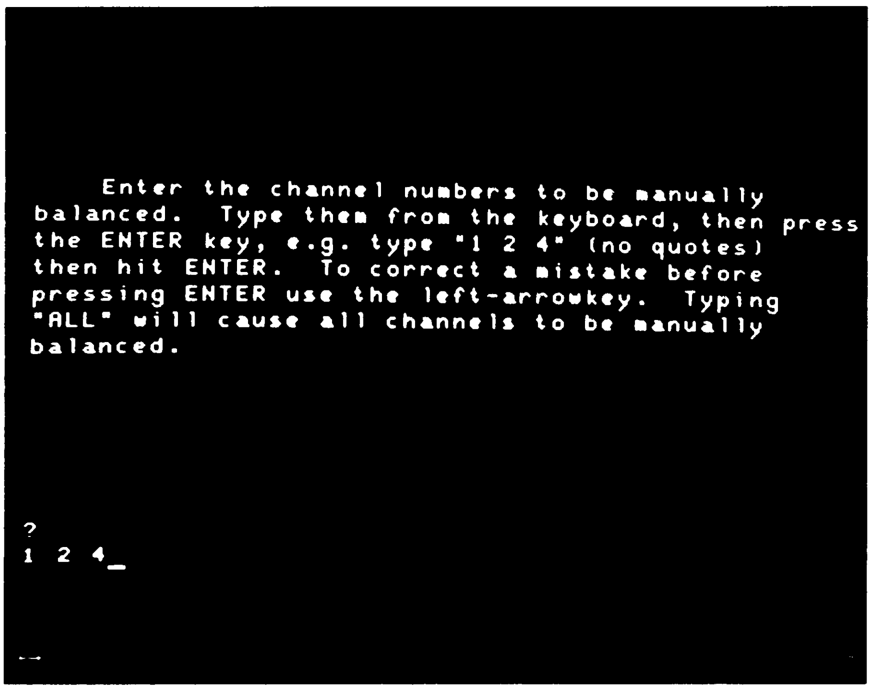

Figure 35

STEP 29

Releasing the main data handling program.

At this stage you have answered all of the preliminary receiver setup questions, and if you are happy with the setup so far you can initiate the main data taking program. The text and keys in Figure 36 will now be displayed giving you the choice of returning to the beginning of the setup procedure, [Restart], or going on to the main program, [Ready]. Pressing [Ready] will send you to step 3. The [Change] key is shown in anticipation of its function in step 3, but it will not do anything until the [Ready] key is pressed.

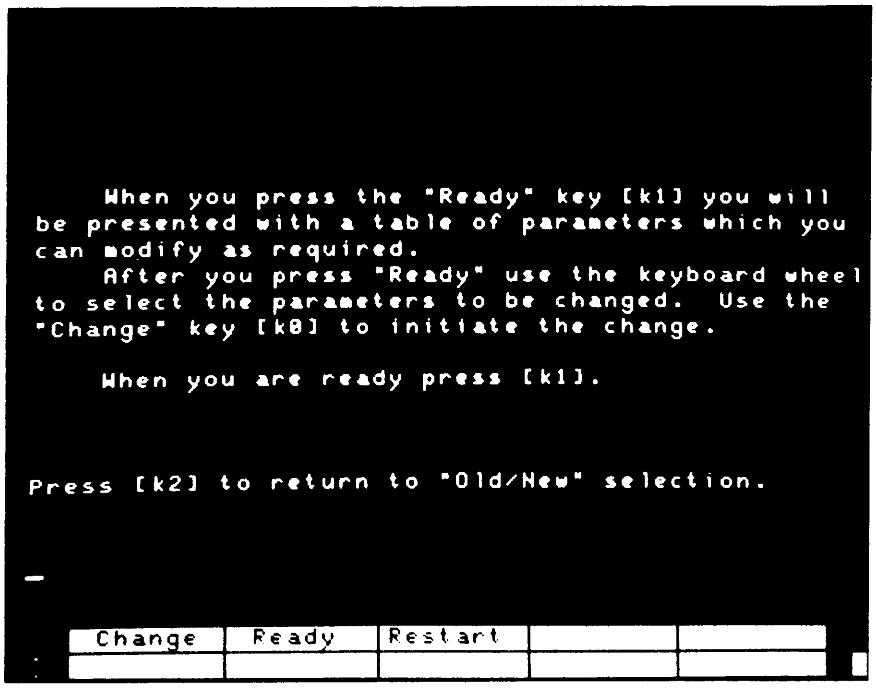

Figure 36

The main program will take a few seconds to load from disk before which all of the receiver setup parameters so far specified will be recorded in your program file.

Setting up the DCR from Scratch

What controls the DCR, and what does the DCR control?

The Digital Continuum Receiver is designed to have a minimum of interaction with the telescope computer. The only commands that it receives from the computer are start and stop scan signals. No information such as integration times or cal values is sent to the DCR from the telescope computer; all of this must be entered through the DCR calculator keyboard as described in step 3. There may be one or two circumstances where the same information may have to be given to both the DCR and the telescope computer, but this amount of duplication has not warranted the construction of a full, two-way communication channel between the two processors.

Data are sent to the telescope computer from the DCR on a 16-bit bus. These data are sent on this bus only during a scan and always have the same general sequence. At the start of a scan a header containing between 21 and 48 16-bit words are sent to the computer, and, thereafter, blocks of between 2 and 9 words (depending on the number of channels) are transmitted for each integration period until the scan ends. Since the data must be transmitted after each integration is finished, an interrupt is sent by the DCR at the center of each integration to tell the computer when to record time and telescope position information to be associated with the current integration. The header contains all of the calibration and receiver data that may be needed in later data reduction.

Except for the rare instance when the DCR is slaved to another piece of observing equipment, such as the autocorrelator, the front end cal and beam or load switches are controlled by the DCR. The only signals received from the front end by the DCR are the IF or detector signals.

Receiver to DCR hookup

Since there are a fair number of wires to be connected to the DCR rack and a number of switches and signal levels to be set, this section is written in the form of an expanded check list. Except for the power and computer cables, all of the connectors mentioned are on the back of the top of the DCR rack.

1. Connect power to the rack through the recessed connector on the top of the rack.

2. Feed the multipin connector and cable from the telescope computer through the rectangular hole in the top rear of the DCR rack, and plug it into the far right hand connector (facing back of rack) on the back of the digital drawer just below the calculator. There may be a plug already on this connector from the manual start/stop scan control switches. Disconnect it and lay it in the bottom of the rack.

3. Connect the SIG or $\overline{\text{SIG}}$ output port (TTL sig = high or sig = low, respectively) to the front end signal/reference control if the receiver has such a switch. If the 140-ft nutating subreflector is being used, connect the ADV SIG or $\overline{\text{ADV SIG}}$ output port to the subreflector position control. The uninverted outputs are the most commonly used.

4. Connect the CAL or $\overline{\text{CAL}}$ output port to the front end cal control. The most commonly used is $\overline{\text{CAL}}$. The blanking output and external inputs normally are not connected to anything.

5. Connect the appropriate number of chart recorders to the chart output ports starting with CR1.

6. Connect the appropriate number of receiver outputs to the type N or three pin connectors.

7. If the detector inputs are used, set the SQ. LAW DET. INT/EXT switches to EXT. If the IF inputs are used, set these switches to INT.

8. Set all of the GAIN switches to 1.

9. Set all of the POLARITY switches to + unless you are using a nonstandard negatively-polarized detector.

10. Set the TIMING SELECT switch next to the large meter below the calculator to INTERNAL.

11. If IF inputs are used, make sure that the appropriate bandpass filters, if any, are installed in the DCR IF amplifier drawers.

12. Set the METER SELECT switch below the calculator to "A" TOTAL POWER and, if detector input is used, adjust the channel 1 receiver detector level to about 1 volt (10 on the large DCR meter). If IF input is used, adjust the IF attenuator on channel A of the DCR IF drawers for 1 V on the meter. The amplifiers and attenuators in this drawer may have to be recabled to get the signal level within the adjustment range of the switched attenuator. Repeat for all other receiver channels using meter switch positions B-D. The DCR will perform satisfactorily with detector levels between about 0.3 and 5.0 V, but best dynamic range margin is obtained with an average level of 1.0 volt.

Starting the calculator

All of the DCR programs are on the disk labeled "Standard DCR Programs". Put this disk into the slot to the right of the CRT display with the label up and toward you. With the disk all of the way in, close the disk drive door.

If the calculator is on, hit the [PAUSE] key, and type the phrase LOAD "RCVRMENU" (with quotes) and press the [EXECUTE] key. If the calculator is off, turn it on with the push switch on the right below the keyboard, and this will automatically load the "RCVRMENU" prompting program. Setup of the DCR may now begin as described in step 18 and those that follow.

<u>Possible Hangups and Their Remedies</u>

This section lists a number of problems which have been encountered during the operation of the DCR at the telescopes. This list may be useful in diagnosing difficulties associated with the DCR.

1. <u>The measured system temperature and radio sources are negative:</u>

   The cal control signal is probably inverted. Move the cal control cable from $\overline{\text{CAL}}$ to CAL or vice versa.

2. <u>Radio sources are negative but the system temperature positive:</u>

   The signal/reference control is probably inverted. Move the sig/ref control cable from $\overline{\text{SIG}}$ to SIG or vice versa.

3. <u>Very high and erratic system temperatures and data overflows during a scan:</u>

   The cal is probably not being driven by the DCR.

4. <u>The average ΔTrms (meas) is considerably greater than ΔTrms (theo) when the telescope is not moving:</u>

   The signal/reference switch rate may be resonating with 60 Hz or with the refrigerator displacer frequency (1.2 Hz). The sky temperature may be fluctuating rapidly due to rain or heavy clouds. The bandwidth used to compute Trms (theo) may be too large.

5. <u>Strong sources fold over in the computer output data:</u>

   The "Computer data F.S. (K)" number is probably too small. Change it by pressing the [Params] key, and follow the procedures from step <u>2.</u>

   <u>or</u>

   The cal may not be being driven by the DCR in which case the system temperature will also be too high. Connect the cal control signal to the front end.

6. <u>The DCR will not respond to a "start scan" from the telescope computer:</u>

The "Timing Select" switch may be on "EXTERNAL". Switch it to "INTERNAL". The multiwire computer cable may not be a valid one for the DCR. The calculator may be stopped or not have a program loaded. The telescope computer may require an integration time which is an integer multiple of 0.1^s.

7. <u>The DCR will not respond to a "stop scan" signal:</u>

Two start scan signals in a row may have been received. Send two stop scan signals without a start scan between them.

8. <u>The scans are the wrong length:</u>

The telescope computer may be using the integration time set on the operator's panel to compute the expected number of integration periods, and this integration time does not agree with the one used by the DCR.

9. <u>"ONE OR MORE SAMPLES MISSED OF LAST SCAN!" message on CRT:</u>

The integration time is too short for the calculator to keep up. Increase the integration time slightly.

10. <u>The calculator does not enter the idle mode after the receiver program is loaded:</u>

The "Timing Select" switch may be set to "EXTERNAL". Set it to "INTERNAL". The digital hardware may have come up in an unrecoverable condition when the power was turned on. Disconnect the A/C plug to the chassis below the calculator for about ten seconds and plug it in again. If all of the lights on the front panel of this chassis are out, there is a power problem in the hardware.

11. <u>"ERROR 120 Not allowed while program running" message on CRT.</u>

This is most likely incurred while changing receiver parameters in the table and pressing [ENTER] before the [Change] key. Press [Change] then [ENTER]. This message will also appear if [EXECUTE], [RUN], or [CONTINUE] are pressed while a program is already running. If

[EXECUTE] was intended after typing a LOAD command, press [PAUSE] first. Do this only if you really want to interrupt the DCR operation.

12. <u>"DETECTOR LEVEL TOO LOW ON RCVR(S) ..." message on CRT:</u>

Either the detector or IF signals are not connected to the DCR for the number of channels specified or signal levels are too low. A detector level of 1.0 V is usually best.

13. <u>The chart recorder output is very coarsely quantized:</u>

The gain of the chart recorder was probably turned up instead of changing the chart recorder scale in the calculator.

14. <u>Sources saturate on the chart recorder before the pen goes off scale:</u>

The chart recorder zero has probably been changed instead of using the calculator controls described in step <u>5</u>. Reset the chart recorder zero and gain controls with the [MID] and [TOP] keys and move the pen with the keyboard wheel or one of the other keys.

15. <u>One or more of the "VCO CLIPPING" lights are on:</u>

The detector level is too high or an interference pulse occurred on one of the channels. If necessary, reduce the detector level by adding IF attenuation (or setting the DC gain on the internal detectors to 1). The nominal detector level is 1.0 V (+10 on the large meter scale).

16. <u>Data values stable but far from zero:</u>

Synchronous detector output is probably not balanced. Press the [Auto Bal] key or press [Man. Bal] and follow step <u>13</u>.

CHAPTER III

PRINCIPLES OF OPERATION

There are enough electronics in the Digital Continuum Receiver rack to take four continuum receiver IF signals anywhere between 5 and 500 MHz and convert them into calibrated and integrated radiometer data with time resolutions of about 300 milliseconds or greater. Figures 37 and 38 are functional diagrams of one of four identical channels. These diagrams will be described in sections which correspond to the division of hardware into individual drawers in the DCR rack.

IF Drawers.

The IF drawers contain two, 19 dB gain, 5-500 MHz amplifiers and a 0-10 dB switch variable attenuator for each of the four channels. The amplifiers and attenuator may be wired in any combination by changing the coaxial cables inside the drawer, and fixed attenuators or a bandpass filter may be wired into the drawer. The outputs of the IF drawers are normally connected to the square-law detectors.

The arrangement of filters, amplifiers and attenuators in Figure 37 is not necessarily the best one for every situation. Since the 19 dB amplifiers are quite wide band, it is usually a good idea to restrict the bandwidth ahead of these amplifiers to prevent overload by out-of-band interference. However, if no attenuation is used between the amplifiers, their own wideband noise will produce a signal level of about -50 dBm at the detector input which means that they will add 3% to the receiver system temperature. If both amplifiers are needed, it is good practice to put at least a 6 dB attenuator between them, or, if the full 38 dB of gain is required, put a bandpass filter between the two amplifiers.

Square-Law Detector.

The square-law detector is a standard NRAO design using a BD4 diode operated in its low level square-law region. The detector input power to output voltage ratio is constant to within 1% over an input power range of -48 dBm (50 mV DC output) to -25 dBm (10 V DC output) for the full 5-500 MHz frequency range. The full input level range cannot be used in this system because the voltage controlled oscillators are less accurate below 300 mV and above 9 V DC input levels.

VCO Drawer.

The primary function of the electronics in the VCO drawer is to convert the DC detector signal into a proportional pulse rate which can be counted by the digital integrators. This drawer also contains a number of manual, switch-selectable options as shown in Figure 37.

The internal (INT) detector input is normally connected to the corresponding channel square-law detector in the DCR rack, and the external (EXT) input is normally connected to the BNC and three-pin connectors on the top rear of the rack. The internal detector has a positive polarity. The external detector may have either polarity, and the POLARITY switch must be set in the correct position because the VCO input is unipolar.

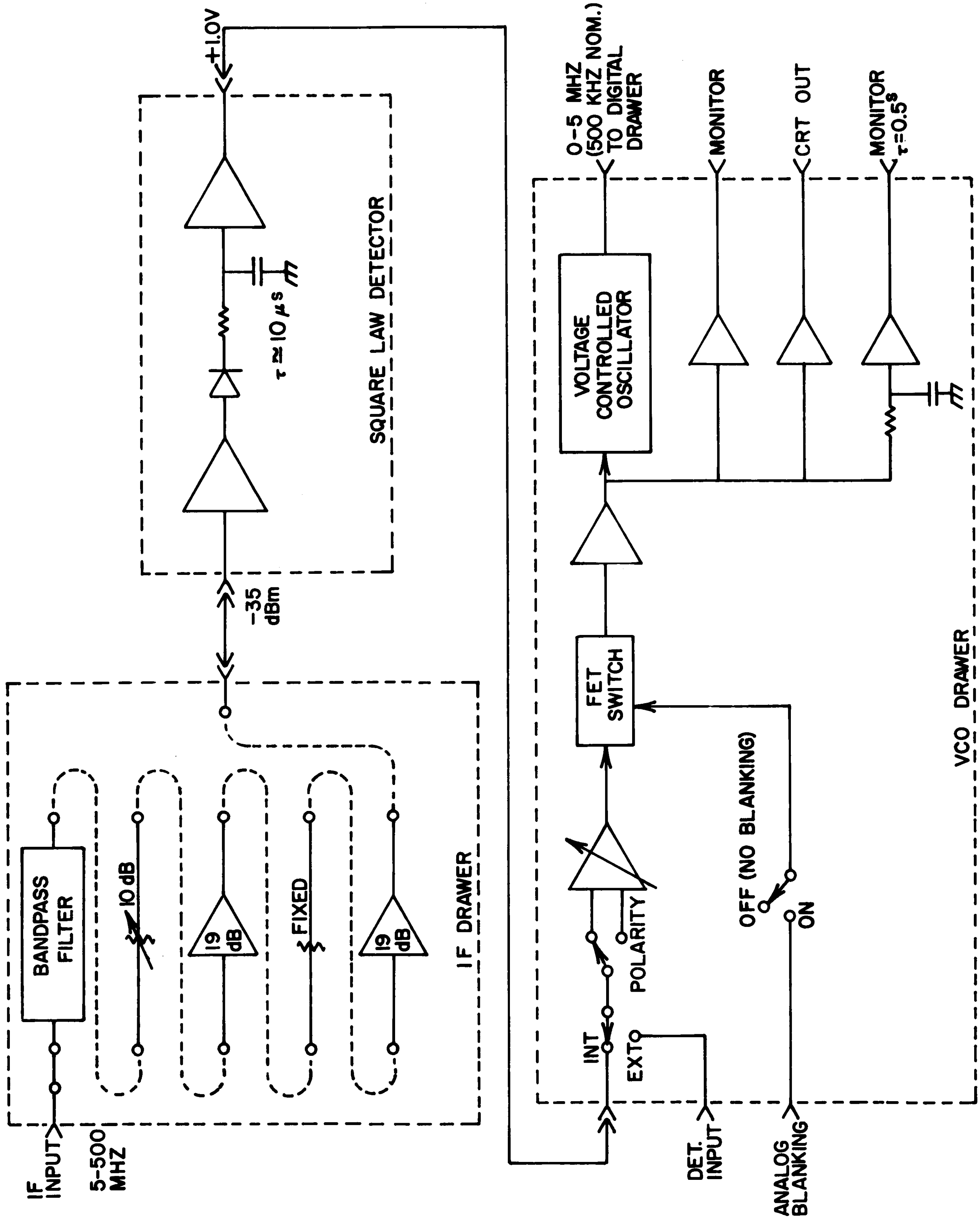
IF INPUT
5-500 MHZ
BANDPASS FILTER
10 dB
19 dB
FIXED
19 dB
IF DRAWER
-35 dBm
SQUARE LAW DETECTOR
τ ≈ 10 μs
+1.0V
DET. INPUT
ANALOG BLANKING
INT
EXT
POLARITY
OFF (NO BLANKING)
ON
FET SWITCH
VCO DRAWER
VOLTAGE CONTROLLED OSCILLATOR
0-5 MHZ (500 KHZ NOM.) TO DIGITAL DRAWER
MONITOR
CRT OUT
MONITOR τ=0.5s

Figure 37

The DC gain of the first amplifier in the VCO drawer may be changed with the GAIN switch on the front panel. The internal detector and most of the other NRAO square-law detectors produce the correct DC level for the VCO, so the gain is normally set to 1.

The FET switch may be used to suppress transients which occur at the beginning of each signal/reference switch phase. The "BLANKING" port on the back of the digital drawer should be the only source of blanking signal for the FET switch. Under this condition the operation of the FET switch has no effect on the data processed by the calculator because the digital integrators are inhibited during the blanking interval. The FET switch blanking is normally turned off unless the $\tau = 0.5^s$ monitor port is being used.

There are three buffered ports which may be used to monitor the total power signal applied to the VCO. One of these has a 0.5^s time constant RC filter so that it may be used with a chart recorder.

The voltage controlled oscillator is a pulse generator whose pulse repetition rate (frequency) is proportional to its DC input voltage. The ratio of its input voltage to output frequency is constant to within 1% for input voltages between 0.3 and 9 volts. Its output frequency is nominally 500 kHz with a one volt input, its response time is equal to one pulse interval, and its overload recovery time is about 5 μs. The 500 kHz frequency produces an amplitude quantization which is smaller than the rms fluctuations on a detected 1 GHz IF bandwidth signal for integration times greater than about 4 ms.

Digital Drawer

The diagram in Figure 38 is a functional representation of the digital portion of the DCR, although the actual hardware and control logic is considerably more complex. The heart of the digital section is the bank of four pulse counters or integrators which are connected one at a time to the output of the VCO in a programmed sequence in synchronism with the load or beam switch and the calibration noise signal. The counter sequence is always top to bottom starting with any one of the four counters and ending with $\emptyset_0$. The two commonly used sequences are

$$\emptyset_3\ \emptyset_2\ \emptyset_1\ \emptyset_0\ \emptyset_3\ \emptyset_2\quad \ldots\ \text{(4-phase)}$$

and

$$\emptyset_1\ \emptyset_0\ \emptyset_1\ \emptyset_0\ \emptyset_1\quad \ldots\ \text{(2-phase)}.$$

The number of phases per cycle and the length of each phase are set by the calculator from the observer-specified detector selection and switch frequency. Phases $\emptyset_0$ and $\emptyset_2$ are normally signal phases and $\emptyset_1$ and $\emptyset_3$ are reference phases, so $\emptyset_0$ and $\emptyset_2$ are logically ORed together to produce a sig/ref control labeled SIG.

Also, an advanced sig/ref signal is provided for the situation where the front end switch has a lot of inertia, e.g., the nutating subreflector on the 140-ft. In this case better synchronization with the integrators is obtained by sending the switch command slightly ahead of the integrator change. The amount of advance is controlled through the calculator and is best set by watching the actual subreflector position and the blanking signal on the dual trace oscilloscope in the DCR rack.

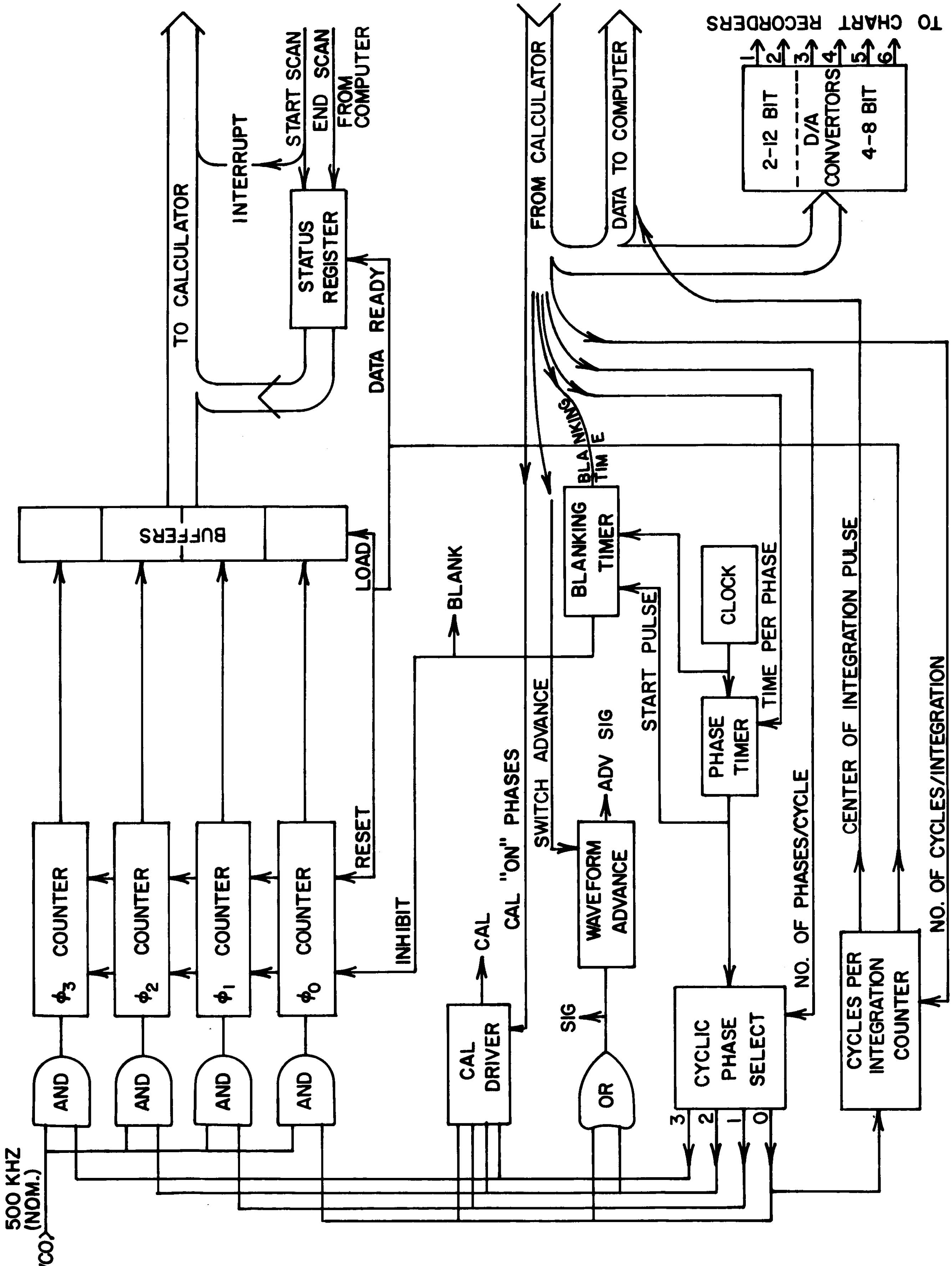
TO CALCULATOR
INTERRUPT
START SCAN
END SCAN
FROM COMPUTER
STATUS REGISTER
DATA READY
FROM CALCULATOR
DATA TO COMPUTER
TO CHART RECORDERS
2-12 BIT
D/A CONVERTORS
4-8 BIT
1
2
3
4
5
6
BLANKING TIME
BUFFERS
LOAD
BLANK
BLANKING TIMER
CLOCK
TIME PER PHASE
START PULSE
SWITCH ADVANCE
PHASE TIMER
CENTER OF INTEGRATION PULSE
NO. OF CYCLES/INTEGRATION
ADV SIG
WAVEFORM ADVANCE
CAL "ON" PHASES
NO. OF PHASES/CYCLE
RESET
INHIBIT
ϕ_3 COUNTER
ϕ_2 COUNTER
ϕ_1 COUNTER
ϕ_0 COUNTER
CAL
CAL DRIVER
SIG
OR
CYCLIC PHASE SELECT
CYCLES PER INTEGRATION COUNTER
AND
AND
AND
AND
3
2
1
0
500 KHZ (NOM.)
VCO

Figure 38

The calibration signal can be programmed to turn on during any of the integrator phases, although $\emptyset_0$ is the most common cal phase. The integration counters can be inhibited by a blanking signal at the beginning of each phase period to ignore detector transients caused by front-end switch transitions. The amount of blanking is set by the calculator as requested by the observer. The blanking signal is wired to ports at the rear of the digital drawer for monitoring or for driving the FET switch in the VCO drawer. Blanking will be properly executed by the digital hardware with nothing connected to the blanking output ports.

The integration period is determined by the cycles/integration counter which is set by the calculator from the observer-specified integration period and switch frequency. The cycles/integration counter is triggered at the end of each $\emptyset_0$, and when the proper number is reached the integration counter values are stored in buffers, the counters are reset, and a status flag is set to tell the calculator that the buffers have new data ready. The calculator is responsible for monitoring this flag after it has finished the calculations on the data from the previous integration period.

The status register contains two additional bits of information: whether a start scan signal has just been received from the telescope computer or whether an end scan signal is present. The start scan signal also generates an interrupt signal which causes the calculator to start sending data to the computer as soon as it can. The end scan condition is not recognized until the end of a set of calculations for an integration period during a scan.

Data from the calculator can be routed in one of three directions: to the hardware to set up the counter and front-end control sequence, to the chart recorder digital to analog converters (D/A's), or to the telescope computer. Hardware instructions are sent at the beginning of a scan and at the beginning of an idle mode between scans. The D/A converter inputs are changed after every integration period both during and between scans as long as the calculator is not occupied with observer input. Data to the computer consists of a header at the beginning of each scan and a block of data after each integration period until the scan ends.

A center of integration pulse is sent directly from the digital hardware to the telescope computer to tell it when to sample time and telescope position to be associated with the current integration.

The Calculator

The algebraic processor for the DCR is a Hewlett-Packard 9826 desktop calculator with a 16-bit full duplex binary interface. It has an alpha-numeric and graphics display for data display and input prompting, an 80-column printer for parameter logging, and a full keyboard with special function keys for operator/observer control.

The 9826 is programmed in extended BASIC. Programs and data are stored on a 5 1/4" magnetic disk. Typically, 12-digit arithmetic and 16-bit I/O operations take about a millisecond, and all of the processing necessary for each integration period requires between 100 and 400 ms depending on the number of receiver and chart recorder channels and on the complexity of computations for each receiver configuration. After entering all of the DCR setup parameters the calculator will test the calculation time for one integration against the specified integration time and may elect to delete one or more of the unessential functions such as data checking, CRT display, or chart recorder output. If the integration time is too short to send data to the telescope computer an error message is displayed.

Chapter IV

CONTINUUM RADIOMETRY TECHNIQUES

A general assumption in radio astronomy is that low noise receiver gains and conditions surrounding a radio telescope are not stable enough to measure weak radio sources with a simple total power receiver/detector system. Hence, a number of switching and gain stabilization schemes have been devised. Different observing conditions require different stabilization methods, so if you are not aleady familiar with the available radiometer configurations please take the time to scan through this section. Receiver stability has improved considerably in the last few years, so there may even be situations where the greatest sensitivity will be obtained with a total power system.

Contributors to unwanted receiver output fluctuations:

Fluctuation spectra.

Continuum radiometer outputs are most familiar in the amplitude-time coordinates, and much of what follows will be discussed as time phenomena. However, in coping with receiver and environmental instabilities, power spectra of detector output fluctuations (amplitude vs. frequency) are often very informative, so the power spectrum concept will also be incorporated in the following discussion. Some periodic and even some apparently random receiver instabilities can be isolated in the subaudio frequency domain and avoided with the proper switch frequency.

In the frequency domain a front end switch becomes a modulator, a synchronous detector is a mixer, an integrator is a low pass filter and baseline removal is a high pass filter. The only slightly peculiar element in the receiver system is the square law detector which acts like a mixer, but, instead of being driven by an LO, it mixes, multiplies or correlates with one another all incremental frequency bands within the IF passband. The result for white noise and a square IF passband is a triangular shaped detector output spectrum with a zero-power intercept at the frequency equal to the IF bandwidth. The triangular shape is due to the fact that there are more close than wide frequency separations in a passband. If the IF bandwidth is much greater than any postdetection (PD) frequencies of interest the slope of the white noise, PD spectrum can be ignored, as it will be here. The PD spectrum of a perfectly stable total power receiver will have a spike at zero frequency equal to the square of the DC output voltage, and above zero frequency the noise baseline will have a power per unit bandwidth proportional to (ΔT_{rms}), the output noise given by the radiometer equation

$$\Delta T_{rms} = \frac{T_s}{\sqrt{Bt}} = \frac{T_s\sqrt{2\Delta\nu_{PD}}}{\sqrt{B}} \qquad (1)$$

where

T_S = system temperature,

B = predection bandwidth,

t = postdetection integration time*

and $\Delta\nu_{PD}$ = postdetection bandwidth, $\Delta\nu_{PD} = 1/2t$.

* Note that $t \neq \tau$ of a RC integrator, but it is equal to the integration time of an ideal integrator as is used in the DCR.

The $(\Delta T_{rms})^2$ baseline is defined as the fundamental detection limit of a radiometer. Any number of instabilities can raise the PD spectral power, particularly below a few tens of Hz, and it is the purpose of good receiver design to reduce the added power and the purpose of radiometer switching to avoid what cannot be eliminated.

Figure 39 shows two characteristic types of detector output fluctuation spectra: periodic fluctuations which create spectral peaks and 1/f noise for which deviations from ideal white noise are most severe at low frequencies. Some of the causes of these fluctuations will be summarized here.

Receiver gain and temperature.

It is normally difficult to distinguish between receiver gain and receiver noise temperature instabilities at very low levels, but sometimes this distinction can be important such as in a noise adding system where the gain is stabilized but temperature fluctuations still show up in the output. There is little information about the relative importance of these two sources of instability, and the relative importance probably varies from system to system.

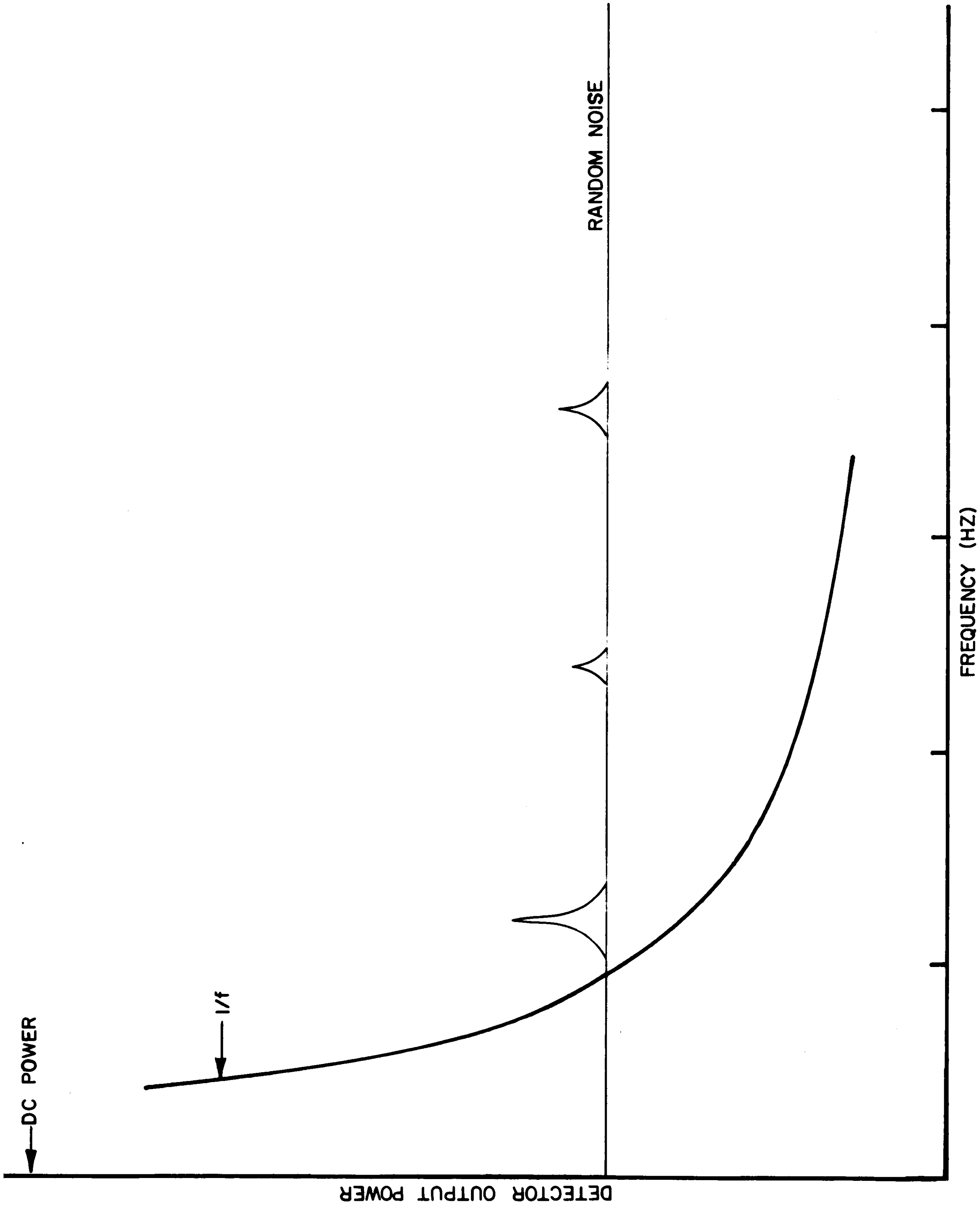
DC POWER
1/f
RANDOM NOISE
FREQUENCY (HZ)
DETECTOR OUTPUT POWER

Figure 39

In the absence of mechanical vibrations or periodic thermal influences, most receiver instabilities roughly have a 1/f spectrum. Parametric amplifiers which were prevalent in low noise receivers until recently had significant PD power up to a few tens of hertz. More modern FET and maser amplifiers often are stable enough to be white noise limited down to 1 Hz or less.

The refrigeration system (CTI 1020 and 350) used with most radio astronomy receivers causes mechanical vibrations and thermal cycling with a period of 1.2 Hz (60 Hz line frequency), and this frequency and its harmonics can be quite prominent in the PD spectrum. Here again, more modern receivers are less susceptible to refrigerator influences, but some caution is still necessary to avoid synchronous detector switch frequencies near the first few harmonics of 1.2 Hz. When using a switch frequency near a significant refrigerator cycle harmonic the passband characteristics of the integrator after the synchronous detector could be quite important in filtering the refrigerator effects out of the data.

Atmosphere.

Above a few GHz, condensed water (fog and clouds) and the 22 GHz water vapor resonance cause quite variable RF absoprtion in the atmosphere. Absorption in the clouds is proportional to $1/\nu^2$ and is significant above about 3 GHz. Under very heavy cloud conditions as much as a few degrees can be added to the system temperature at 5 GHz, and heavy rain can add even more. Above about 15 GHz resonant water vapor absorption becomes significant adding as much as 20 K to system temperatures at 22 GHz under warm, humid conditions.

Power spectra of atmospheric noise fluctuations show increasing amplitude at lower PD frequencies in the same sense as 1/f noise. Very little documentation exists on the amplitude and spectra of atmospheric noise fluctuations at levels common to radio astronomy, but some rules of thumb have evolved. On time scales of about ten seconds, peak to peak atmospheric fluctuations can vary from a few hundredths to nearly ten Kelvins at 19 GHz and from a few thousandths to about one Kelvin at 5 GHz. Except under poor conditions above 15 GHz, the atmosphere appears to contribute less than 0.01 K to the post detection noise power above 5 Hz or so with a post detection bandwidth of 1 Hz. However, these are very rough numbers. Compensation for atmospheric noise (beam switching) is commonly used for continuum measurements above 3 GHz.

Antenna spillover and scattering.

As much as 10% of the integrated power pattern of a reflector antenna falls more than 20° from its main beam, and as much as 30% is outside a radius of a few beamwidths. A significant portion of this spurious response can be intercepted by the ground and can add 5 to 15 K to the system temperature. This noise is at least slightly variable with antenna position. For most small angular scale source measurements, antenna spillover and scattering are of little consequence except as they affect the system temperature in the radiometer equation, but extended sky maps can be distorted by a significant fraction of a Kelvin if changing ground and atmospheric noise pick up are not corrected for.

Background point sources (confusion).

Small angular diameter continuum radio sources become more and more numerous with decreasing apparent intensity. At the intensity above which there is one radio source per 100 antenna beamwidths there is a significant chance that a detected source is the combination of two weaker sources. This intensity is often called the confusion limit of the antenna. At weaker intensities the sources merge into a nearly continuous background radiation which fluctuates randomly with position and can be characterized by an rms confusion noise level. The confusion limit is often set to be five times the rms confusion noise and both are proportional to the main beam diameter and approximately proportional to $\nu^{-0.7}$, at centimeter wavelengths, where ν is the observing frequency. A benchmark is the 300-ft telescope which has an rms confusion noise of about 3 mJy at 5 GHz.

Total power radiometry.

The total power radiometer, in principle, is the most sensitive of the continuum receiver configurations for a given bandwidth, integration time and system temperature. Its sensitivity limit is specified by equation (1). This technique is not frequently used because it relies on a total system stability of a part in 10^4 or better over time scales of an observation, typically a minute or more. However, receivers are more stable now than in the past, so total power observing should at least be considered, particularly for fast scanning of small sources.

Noise adding radiometry.

There are two techniques both of which have been called noise adding radiometry (NAR). The first is very much like load switching where a strong noise signal is added to the receiver input during the reference phase of the synchronous switch cycle to cover up the signal from the antenna. The detector output is treated in much the same way as if a hot reference load were used instead of added noise. The synchronous detection method is discussed in the next subsection under load switching.

The second form of noise adding radiometry is a receiver gain compensation scheme which, for a finite amplitude of added noise, has a slight sensitivity advantage over the first form. In this subsection only the gain compensation form of NAR will be dealt with. An advantage of NAR over load or beam switching is that a lossy switch does not have to be put in the signal path ahead of the low noise amplifier. A disadvantage is that NAR only compensates for receiver gain fluctuations and does not cancel changes in receiver or sky noise temperature.

A detailed discussion of the sensitivity of NAR is given by Yerbury (Rev. Sci. Inst., Vol. 46, p. 169). In this article he shows that the sensitivity of NAR can be considerably better than is theoretically possible with load switching *if* the receiver gain fluctuations are slower than the output data integration time. However, this sensitivity advantage is of limited practical value because either receiver gain fluctuations are relatively fast or they are slow enough to use straight total power. Data samples adjacent in time are not completely independent when the gain compensation time constant is longer than the data integration time.

Figure 40 shows the basic elements of a noise adding radiometer. The relative gain of the system is measured by taking the difference of the signal and reference integrators which are connected to the detector in synchronism with the noise source being off and on, respectively. The radiometer output is proportional to the signal integrator divided by the reference-signal difference. Since the gain is most accurately determined with a strong noise source, it is often necessary to synchronously switch an attenuator into the signal path to keep the detector in its accurate square-law region. The reference integrator value would then have to be multiplied by the attenuation constant before being used in the gain calculation.

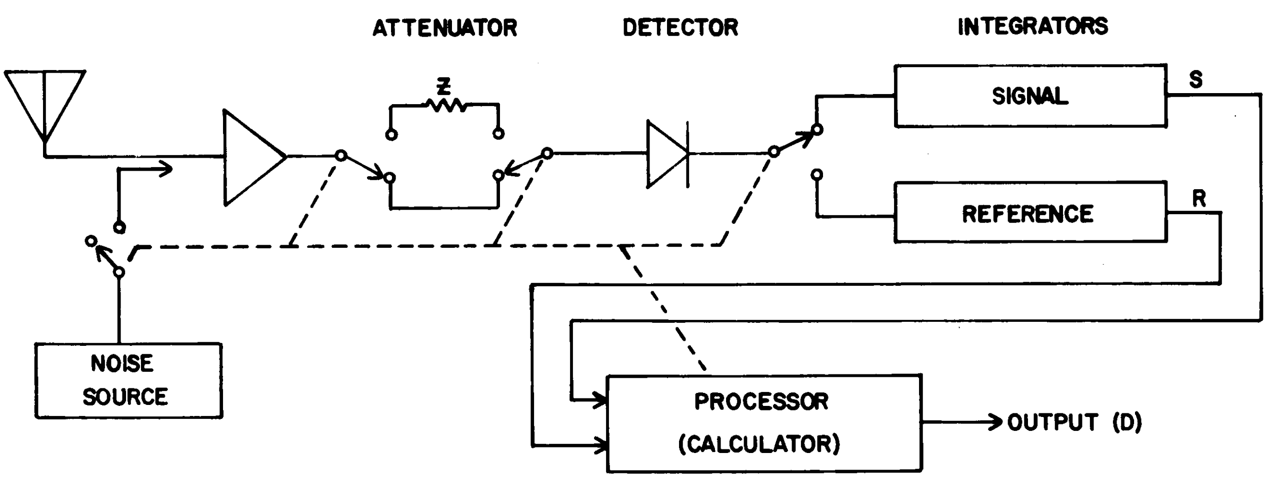

Figure 40

In the processor the relative gain is given by

$$G = (ZR - S)/E \tag{2}$$

where

Z = the fixed attenuator constant,

R = the reference integration value,

S = the signal integrator value,

and E = the gain at the start of the scan in the same units as R and S.

The output signal is then

$$D = (GS - A)/K \tag{3}$$

where

A = the signal integrator value at the start of the scan,

and K = the calibration factor in counts per Kelvin.

The values of Z, E, A and K are constant during a scan so the noise on the output will be determined by the noise on R and S. The fractional rms noise on R and S is $1/\sqrt{Bt_{R,S}}$, where B is the predetection bandwidth and $t_{R,S}$ is the integration time of the R or S counters. The fractional noise on G will be smallest if $ZR \gg S$. Hence, a strong noise source is required. The relative amount of integration time spent on signal and reference determines the relative fractional noise on G and S in Eq. (3), and the minimum fractional noise on D will occur when $t_R \simeq t_S$. Table 1 gives a rough idea how the sensitivity is affected by the fact that ZR cannot be infinitely larger than S by giving the factor by which ΔT_{rms} in Eq. (1) is multiplied to get the NAR detection limit assuming $t_R = t_S$.

TABLE 1

Radiometer equation constant for a gain compensating NAR for different ratios of noise source intensity to system temperature

T_{NS}/T_{sys}	ΔT (NAR)/ΔT (Total Power)
∞	2.0
10	2.11
8	2.14
6	2.19
4	2.29
2	2.65
1	3.46

If possible, the noise switching frequency should be faster than any gain instabilities in the receiver. If this is not possible, the switching frequency should at least avoid any narrowband features in the receiver's postdetection spectrum.

Load switching.

Load switching is one of the oldest methods of receiver stabilization in radio astronomy, and is often called Dicke switching after one of its first users, R. H. Dicke. As the name load switching implies, the receiver input is switched between the antenna feed and a stable resistive load as shown in Figure 41. The useful output is the difference between the signal and reference integrators.

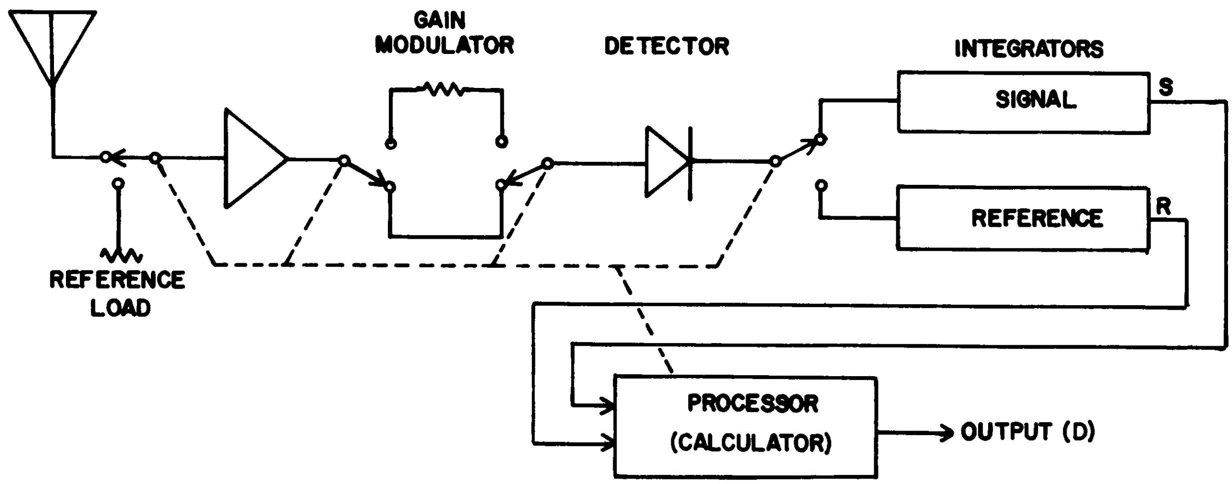

Figure 41

The immunity of the load-switched system to receiver gain fluctuations depends on equal levels in the signal and reference integrators. Ideally, the amplitude of the noise from the reference load should be equal to the total noise amplitude from the antenna. This requires that the reference load have a physical temperature equal to the equivalent antenna temperature which is usually in the range of 10 to 30 K. This is possible with cooled receivers, but thermal stability of the load has proven more difficult to achieve at low temperatures without active compensation because most metals lose their thermal inertia at very low temperatures.

In the absence of a low-temperature reference load, balance in the output integrators can be achieved either by adding noise to the antenna signal path or by reducing the gain of the system during the reference half of the switch cycle. Adding noise to the signal path would degrade the system temperature, so this balancing method is seldom used with load switching. However, gain modulation is a standard technique and can be implemented with a controllable IF attenuator when an analog synchronous detector is used or with a multiplication constant applied to the reference integrator value when a digital demodulator such as the DCR is used.

At first glance it would seem that using a warm reference load would degrade the system performance because of a higher reference system temperature. This is not the case in a gain balanced system, however, because the _fractional_ noise on the signal and reference integrator values is equal to $1/\sqrt{Bt}$ and is independent of input noise level. If the integrator levels are balanced, and the signal and reference times are equal, the noise on the signal and reference integrators will be equal regardless of whether the antenna and reference temperatures are equal, _or_ the reference temperature is higher, and the gain is reduced to achieve balance. Equal noise and receiver gain immunity would not be realized if a DC offset is subtracted from the reference integrator to produce balance.

One penalty of using gain modulation to compensate for unequal reference and antenna temperatures is that the system will respond to variations in the noise temperature of the receiver behind the load switch in proportion to the compensating gain imbalance. In the worst case of a very hot reference load, any receiver temperature variation would show up as an equivalent synchronous detector output signal. Normally the gain imbalance is not required to be so severe, and receiver temperature is more stable than receiver gain. However, the relative importance of receiver temperature and gain instabilities are not well studied.

Recently it has been suggested that the input port of a low noise, uncooled FET amplifier would make a good low temperature load without the necessity of a low physical load temperature. This scheme would be advantageous only if the noise temperature of the load amplifier were considerably more stable than the noise temperature of the receiver itself.

The sensitivity of an ideal load switched system is poorer than a perfect total-power receiver by a factor of two.

$$\Delta T_{rms} = 2\ T_{sys}/\sqrt{Bt} \tag{4}$$

where t is the total integration time on signal plus reference less blanking time. The factor of two comes from the product of two $\sqrt{2}$'s; one because only half of the integration time is spent on signal and the second because two equally noisy signals are being differenced.

The signal-reference switch rate should avoid any characteristic receiver instability frequencies (e.g., 1.2 and 60 Hz and their harmonics) and should be higher than the frequency where 1/f noise is significant for the particular receiver, if possible.

<u>Beam switching.</u>

The receiver gain variation immunity advantages of load switching plus substantial cancellation of atmospheric noise fluctuations can be achieved by replacing the reference load in Figure 41 by an offset antenna beam. This can be done with an offset feed or by tilting the subreflector in a Cassegrain system. Since the noise received by the front end will be very nearly equal in the signal and reference halves of the switch cycle the system is intrinsically nearly balanced. The gain modulator is still useful, but gain ratios are close to unity.

There are two, sometimes conflicting, balance conditions in a beam switching radiometer. To cancel atmospheric fluctuations, the amount of power received from the atmosphere in the general direction of the main beam should be the same in the signal and reference beam. If there were higher resistive or reflective losses in the reference beam path than in the signal beam path, the gain would want to be <u>increased</u> in the reference half-cycle to compensate for the loss in atmospheric noise power. Conversely, higher noise input to the front end which would call for a gain <u>reduction</u> in the reference half cycle to maintain receiver gain fluctuation immunity. One way around this conflict is to balance the gain for equal power from the atmosphere and balance the noise input level by adding noise or resistive attenuation to the signal beam path.

Often, the main uncertainty in balancing a beam switched system is in deciding when the atmospheric noise contribution is equal in the two halves of the switch cycle. Measuring the aperture efficiency in the two beams can be misleading because an off-axis beam usually has considerably reduced aperture efficiency, but the integrated power from the main beam and its first few sidelobes does not decrease significantly with beam offsets of less than five beamwidths. In principle, excess resistive losses in the reference path are most simply compensated by adding a small amount of resistive attenuation to the signal path ahead of the switch because this brings both the added loss noise and atmospheric noise power closer to balance simultaneously, but the radiometer performance would be just as good with noise injection and a non-unity gain ratio. A fairly detailed understanding of the path losses and contributors to noise imbalance ahead of the switch will be necessary to decide on the best gain ratio and noise injection amplitude.

The theoretical sensitivity and switch rate considerations are the same for beam switching as for load switching except for the fact that the atmospheric noise fluctuations may require a higher switch rate than would be needed for receiver gain instability.

Gain calibration.

Once the receiver output is stabilized with one of the methods above, the next important task is to calibrate the output in source intensity units. This is usually done in two steps. The receiver gain is calibrated with an internal noise source of known intensity to convert output changes in volts or integrator counts into equivalent antenna temperature changes, and the antenna gain is calibrated by measuring the antenna temperature changes produced by sources of known intensity. Antenna gain is usually a function of antenna position and sometimes other variables, so this half of the calibration procedure will be left to the users' manuals for the individual instruments. The two steps could be combined by calibrating the receiver noise standard directly in units of source intensity, but, since the DCR has no way of determining antenna gain, we shall separate the two steps. The DCR output is in temperature units, and the conversion to flux density is left to the off-line data reduction.

Noise adding radiometry calibrates receiver gain naturally, so it needs no further comment. The other three radiometry methods require a gain calibration which is independent of the stabilization scheme. This calibration can be done intermittently if the receiver gain does not vary by more than the required accuracy between calibrations, or can be done continuously by switching on the noise standard (cal) in synchronism with the integrator selection switch.

Intermittent gain calibration with the DCR is done at the beginning of each scan by retaining the gain information computed just before the scan starts. Between scans the DCR operates in an idle mode during which it continuously computes the calibration and other receiver parameters to be sent to the telescope computer in a data block, called a HEADER, at the beginning of each scan. During the scan, the calibration signal is turned off. Gain calibration accuracy depends on the noise standard strength relative to the system temperature and the time spent integrating the data used in the gain computation. The DCR uses a cal duty cycle of 0.25 so the computed gain rms uncertainty is

$$\Delta G_{rms} = \frac{2\sqrt{2}\, T_{sys}}{T_{cal}\sqrt{B\,\tau_g}} \tag{5}$$

where B = receiver bandwidth in Hz and

τ_g = gain integration time.

As an example, if $T_{sys}/T_{cal} = 0.05$, $B = 100$ MHz, and $\tau_g = 1$ sec, the $\Delta G_{rms} = 0.57\%$.

Continuous gain calibration requires that the noise standard be measured continuously during the scan. This has the disadvantage of increasing the system temperature by the noise standard temperature times its duty cycle, but if the receiver gain varies significantly during a scan the increased calibration accuracy may be worth the small sensitivity loss.

There are two ways the continuously computed gain can be applied to the data: point by point where the gain computed during one integration period is applied directly to the datum for that period, or as a running average where the computed gain is averaged over a specified number of integration periods surrounding each data point before being applied to that datum. The latter method has the advantage of applying a more accurate gain calibration to each point unless the gain varies from one integration period to the next which is unlikely in most cases. If D' is the uncalibrated datum, and G is the relative gain, the calibrated datum will then be

$$D = D'/G \tag{6}$$

which will contain noise from both D' and G. In a balanced radiometer system (load or beam switching) D' will be close to zero so the noise on G will be of little consequence, but if D' is not small, either because of a source in the antenna beam or because of receiver imbalance, the gain uncertainty will add noise to the calibrated data. If we assume that D' is in temperature units and G is near unity, the noise on D' will be

$$\Delta D' = \frac{2\ T_{sys}}{\sqrt{B\ \tau_{int}}} \tag{7}$$

where τ_{int} is the integration period for load or beam switching. The uncertainty on D due to ΔG from Eq. (5) will be

$$\Delta D = D\ \Delta G, \tag{8}$$

and we can combine Equations (5), (7), and (8) to determine at what value of D' the gain and radiometer noises contribute equally to the noise on the calibrated data.

$$\Delta D = \frac{D 2\ \sqrt{2}\ T_{sys}}{T_{cal}\ \sqrt{B\ \tau_g}} = \Delta D' = \frac{2\ T_{sys}}{\sqrt{B\ \tau_{int}}}$$

$$D = \frac{T_{cal}}{\sqrt{2}}\sqrt{\frac{\tau_g}{\tau_{int}}} \tag{9}$$

This says that if the receiver imbalance or source strength is more than about one quarter of T_{cal} the gain uncertainty will add noise to the calibrated data unless $\tau_g >> \tau_{int}$. If ΔG_{scan} is the receiver gain fluctuation during a scan, continuous gain calibration will be advantageous if

$$\Delta G_{scan} > \Delta G_{rms} \tag{10}$$

Note that for a total power radiometer the receiver imbalance is equal to the system temperature, so continuous gain calibration is of little use unless $T_{cal} >> T_{sys}$. This is the condition for noise adding radiometry.

Appendix I

SOME DEFINITIONS

During the evolution of the DCR a number of slightly ambiguous terms have been used to describe the switching and data taking sequences, and some confusion has occasionally resulted. These terms are necessary to explain the functions of the DCR so the following collection of definitions may be helpful.

The DCR contains four digital counters, designated 0 through 3, any number of which can be connected to the detector in one of four sequences: 3-2-1-0, 2-1-0, 1-0, or fixed to 0. To illustrate the following definitions let us assume that all four counters are in use, the front end has a two position switch which toggles with every counter change, and a calibration noise source fires when counter 0 is selected. See Figure 42.

The PHASE TIME or PHASE PERIOD is the time between the end of one counter interval and the end of the subsequent counter interval. The hardware and control will allow alternate phase periods to be different, but in practice they are usually equal. The phases are denoted by $\emptyset_3$, $\emptyset_2$, $\emptyset_1$ and $\emptyset_0$.

The SWITCH PERIOD is the sum of two adjacent phase periods and usually refers to an on-off sequence of a front end switch.

The SWITCH RATE or SWITCH FREQUENCY in Hz is the reciprocal of the switch period in seconds.

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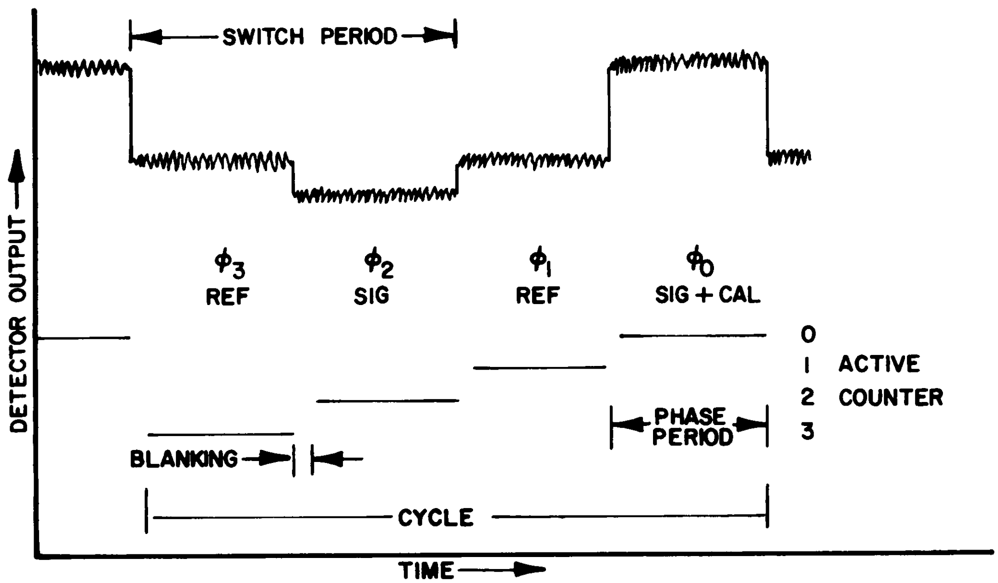

Figure 42

BLANKING is the interval between the start of a phase period and the activation of a counter. This suppresses any transients generated at switch transitions.

IDLE MODE is the normal DCR operating condition between scans during which all data calculations and display functions are performed, but no data are sent to the telescope computer. All of the user control of the DCR parameters is done during the idle mode.

The INTEGRATION PERIOD is one or more cycles, and is the effective sampling interval of the astronomical data. Data are sent to the telescope on-line computer and to the chart recorders once per integration period, typically once per second.

The term NOISE ADDING SOURCE, abbreviated NAS, will be used here to refer to the intense noise source used in noise adding radiometers to stabilize receiver gain. The NAS is distinct from the cal source, because the former is many times the system temperature while the latter is usually only a small fraction of T_{sys}.

A SCAN is an observer-defined series of integration periods usually in the range of ten seconds to several minutes. Scans are often separated by intervals when no data are recorded, say, during a telescope move.

SCAN MODE is the time between start and stop scan signals from the telescope computer during which the DCR sends data to the telescope computer once every integration period. Most of the user control functions are inoperative during the scan mode.

A SIGNAL PHASE refers to the phase during which the front end is connected to the primary antenna feed in contrast to the REFERENCE PHASE when the front end is typically connected to a reference load or offset feed. A CAL PHASE is usually a signal phase during which noise power of known intensity is added to the front end input.

A SWITCH CYCLE is a full sequence of phases. It can be one, two, three or four phases long.

Appendix II

GENERAL SPECIFICATIONS

Number of DC or IF input channels	4
Switch rate	$\leq$ 500 Hz (switch period resolution = 31.35 us).
Integration time	Min = 0.1^s to 0.4^s depending on receiver and number of receiver and chart recorder channels. Max = 32^s.
Phase period	1 to 32767 milliseconds in 15.625 us steps.
Blanking period	Zero to full phase period in steps of 1/64 of phase period.
DC (detector) input levels ...	0.3 to +10 V (typically 1 V) with a DC gain of 1.0.
DC polarity	Switch selectable + or -.
Input sampler	Voltage to frequency converters and digital counters.
DC input resolution	5 x 10^5 counts/sec with 1 volt level.
DC gain	Switch selectable 1, 2, 5, 10, 20, 50, 100.
IF input frequency range	5-500 MHz.
IF input level to square-law detector unit	Approximately -30 dBm.
IF gain available	0 to 38 dB.
Number of digital output channels	Up to 8.

Continued --

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Digital output resolution	16 bits, +- 32,768 full scale.
Internal accuracy of calculation	12 BCD digits floating point.
Control/computation calculator	HP 9826
Number of chart recorder outputs	Up to 6.
Chart recorder resolution	12 bits (4096 levels) for channels 1 and 2. 8 bits (256 levels) for channels 3 to 6.
DC chart recorder level	-5 to +5 V
Front end control logic available on all output functions	TTL, TTL inverted.
Front end control outputs	Sig/Ref, Cal, and Blanking
External control logic (inputs)	TTL
External control inputs	Signal/reference, Cal, Blanking

Appendix III

HEADER SENT TO TELESCOPE COMPUTER

The following is the format for the data contained in the header sent to the telescope computer at the beginning of each scan. Note that this is not the telescope tape or off-line computer header although much of the same information is contained in these other headers in different formats.

16-bit Word #	
1	Number of words to follow in header = 11 + 9 x # of Rcvr channels (47 max).
2	Channel 1 data scale factor (counts/K) {redundant with word 14}.
3	Number of (integrator) counter cycles in the Receiver Setup time (idle mode integration time).
4	Receiver Setup Time (idle mode integration time) in seconds x 100.
5	Integration Period in milliseconds.
6	No longer used (spare word).
7	Blanking time in units of 1/4096 of an integration period (phase).
8	Integrator phase period in milliseconds.
9	Blanking time in milliseconds.
10	Number of Receiver Channels (1 to 4).
11	Hardware status word.
12	Time window for statistics calculations in seconds.
13	Gain modulation factor x 1000 for channel 1.
14	Data scale factor (counts/K) for channel 1.

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16-bit Word #	
15	Relative gain x 1000 for channel 1.
16	Measured data rms x 10,000 (K) for channel 1.
17	Theoretical data rms x 10,000 (K) for channel 1.
18	Computer data scale factor in counts/K for channel N + 1.*
19	Cal value x 100 in K for channel 1.
20	System temperature x 10 in K for channel 1.
21	Bandwidth x 10 (MHz) for channel 1.
22-30	Same as 13-21 for channel 2.
31-39	Same as 13-21 for channel 3.
40-48	Same as 13-21 for channel 4.

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* There can be as many as 8 data channels sent to the computer. If there are N receiver channels (1 to 4) there may be data in channels N + 1 to 2N sent to the computer containing auxiliary gain or total power for each integration. Computer channels 1 and N + 1 would be from the same receiver channel as would 2 and N + 2, etc.

Appendix IV

SPECIAL FUNCTION KEYS

The special function keys are listed here for faster reference to their descriptions in the text. The page numbers in parentheses are secondary references, and those without parentheses are where the functions are most completely described.

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