User's manual for the Algonquin Radio Observatory spectrometer
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NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

USER'S MANUAL FOR THE ALGONQUIN RADIO OBSERVATORY SPECTROMETER

- L. A. HIGGS, C. W. McLEISH, AND T. G. O'NEILL -

OTTAWA

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FIGURES

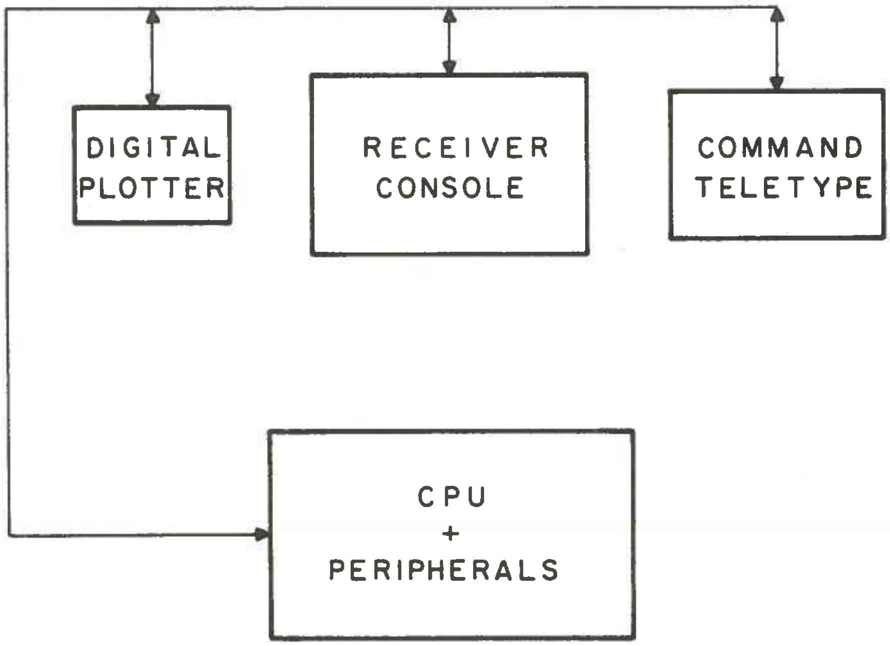

Figure 1.1 Operator - receiver interactive hardware

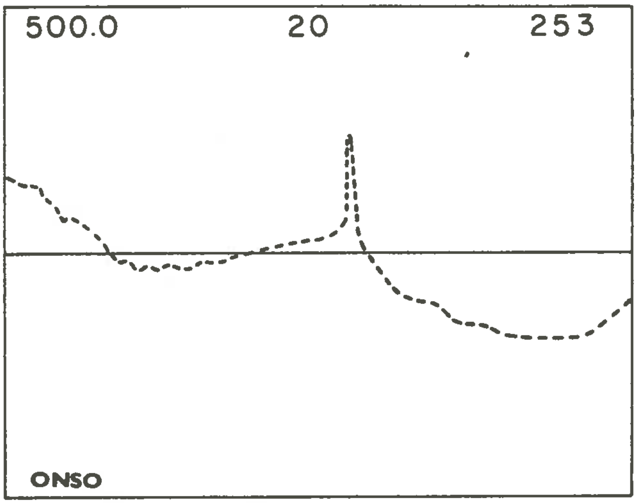

Figure 1.2 A typical display presentation

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I OPERATING PROCEDURES FOR LINE RECEIVER PROCESSOR

No attempt is made in this Section to describe the line receiver front end or the theory of operation of the receiver. The information presented is intended to provide the prospective user with the techniques required to make observations with the spectrometer. For details of hardware, or theory of operation, the reader is directed to Sections 3.5.

1.0 HARDWARE

The hardware with which the operator has to interact is depicted in Figure 1.1. The computer is the heart of the back end of the receiver. It acts as a synchronous detector, an integrator and data acquisition and recording system. It performs processing on the acquired data and presents the results in visual form to the operator. And last but not least it carries out execution of operator initiated commands.

The primary control position is the receiver console which contains the spectrometer control panel and the CRT display as illustrated in Plate 1.1. It is through the receiver console that most of the operator–receiver interaction takes place. A group of the most frequently used commands is implemented via push-buttons on the spectrometer control panel. To initiate a command the operator simply pushes the appropriate push-button. Two push-button commands (EXPAND DISPLAY and SCALE FACTOR) require arguments and these are provided via thumbwheel switches on the control panel. The CRT display is used to present the acquired and processed data to the observer. A digital plotter interfaced to the computer is used to obtain hard copies of the data presented on the display. In certain cases, display data can also be punched onto paper tape for later use. Those commands not implemented with push-buttons are entered by use of the command teletype. This teletype not only provides the command facility for those less frequently used commands but also provides a backup for the push-button commands. The final hardware units with which an operator is to be concerned are the magnetic tape units which are used for system loading and data storage.

1.1 USE OF DISPLAY

The CRT is used to display the 100 channels of information from the receiver and since it is the primary means of presenting information to the observer it is essential that the observer be familiar with the format of the presented data as well as the means of altering it. A typical set of displayed data could appear as in Figure 1.2. The display processor software automatically calculates the average value for the 100 channels and subtracts this average value from the data to be displayed. This results in a trace always centered about zero on the display thus eliminating large offsets which are annoying and troublesome when one attempts to use increased sensitivity. This average value is displayed in the top right hand corner of the screen. The scale factor in display units per centimeter is displayed in the top left hand corner of the display while the number of integrations (in OFSO and ONSO modes)* is displayed in the top center. The mnemonic corresponding to the mode currently in use is displayed in the lower left corner of the screen. Activation of a particular mode push-button causes immediate presentation of the mode mnemonic on the screen as well as the data. Hence one can quickly check what is in the ONSO and OFSO buffers. In the case of the other modes where no data are stored (e.g., DMBL), data of value zero are displayed during the initial integration period.

The operator may wish to alter the form of the presented data so it is easier to study and the following facilities exist for this purpose (see Section 2.3 for a full description of the commands). The display is calibrated at the operator's discretion by the use of the teletype command ICAL x which results in alternative +4 volt and −4 volt signals being applied to the 100 channels if x is non-zero or 0 volts if x is zero. If the observer wishes to expand a portion of the trace, he specifies in the appropriate thumb-wheel switches the low and high channel numbers of that portion to be expanded and then activates the EXPAND DISPLAY push-button. The expand indicator light indicates when the display is in this mode. To return to the normal 100 channel display the operator pushes the RESET DISPLAY button. If an operator wishes to locate the zero line on the scope during an observation he can use the ZERO DISPLAY push-button to present the zero line and then the RESET DISPLAY push-button to return to the previously displayed data. The basic scale factor for the display is operator controlled via a push-button-thumbwheel switch combination. Each position on the thumbwheel switch corresponds to a preset scale factor except for position 9 which can be set by the operator (via a teletype command (SCAL x) to any scale factor desired. The scale factor in display units per centimeter is displayed in the top left corner of the display. For most modes of operation, the display unit is a millidegree; however, other units are used with some commands. At any time, the rms noise on the display (actually on the whole display minus a specified segment) may be calculated using the RMSN command. It should be noted that the 100 channels are always referenced by channel numbers 00 to 99. Certain displayed quantities may have a sinusoidal baseline due to the standing wave set up by reflections between the feed and the antenna (or sub-dish). A sine curve of the proper period for single reflection, fitting the baseline best, can be removed from the display by using the /BASE command. To obtain a good baseline, a combination of the /RMSN (to remove a linear slope) and /BASE commands may be necessary. The corrected display may then be plotted or punched unto paper tape by using the /PDBF command.

1.2 USE OF PLOTTER

The plotter is calibrated in the same manner as is the display. The command ICAL x causes a 4 volt level to be output to the plotter when x is non-zero and a 0 volt level when x is zero. The push-button command PLOT causes the 100 channels currently on the display to be plotted on the digital plotter. Since one inch on the plotter corresponds to one centimeter on the display, the scale factor is directly transferable.

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*See Section 2.1 for a description of the mnemonics.

1.3 OPERATION

When the line receiver program is first loaded into the computer, the user has the option of setting console switch 23 to obtain a brief listing of basic intructions concerning the operation of the processor. It is recommended that every new user make use of this option.

For loading instructions, see Section 1.14a. A checklist of switch settings is given in Section 1.15 for the 2.8cm receiver and the spectrometer.

The following set of commands forms a basic sequence (not necessarily the only one) for producing a spectrum of a source. It is assumed that the computer has been loaded and is running as is the required receiver hardware, that all peripherals have been calibrated to the satisfaction of the operator (see ICAL x), that the desired initial set-up information has been entered (see Section 2.1). The system calibration temperature is selected by positioning the selector lever switch in the CALIBRATE position and operating the INCREASE/DECREASE noise power level switch until one of the two limit lamps (1° or 10°) are lit. Either of these may be preset by the CALT command using the index 2 for 1° position and index 5 for the 10° position (see Section 2.3). The other indices in the table are reserved for future calibration levels. The calibration switch setting is read directly by the computer. Since any display for which the display unit is millidegrees is based upon the selected calibration temperature, one should check which value the computer is actually using. This may be done by typing CALT with no argument.

The push-button sequence is as follows:

(1) SET LEVEL
(2) STOP
(3) DMBL
(4) STOP
(5) ONSO
(6) STOP
(7) DMBL
(7a) NPEQ (for frequency switching only)
(8) STOP
(9) OFSO
(10) STOP
(11) SPEC
(12) PLOT

The SET LEVEL mode is entered so the operator can set up the receiver levels and check to determine if it is operating properly. The number in the top right corner of the display divided by 12.5 is the average signal value in millivolts over the 100 channels and over 5 seconds of integration. A new display is presented every 5 seconds allowing the operator to tweak the level control and check the effect. This mode is terminated by the STOP command when the level is satisfactory.

The DICKE MODE BALANCE mode of operation is entered to balance the receiver using the noise balance control or gain modulator and the information is presented on the display. Every 5 seconds the integrated (for 5 sec) values of signal-reference for the 100 channels is presented on the display with the average value in the top right corner of the screen. The average value in millivolts is obtained by dividing this number by 12.5. When the receiver is balanced the number at the top right of the CRT screen should go to zero. This mode is terminated by the STOP command (see Section 4.4).

The ON SOURCE observing mode is entered next, during which the telescope tracks the source and signal, reference and calibration data are taken. After every minute* the data above are used to calculate a set of 100 temperatures which are stored on magnetic tape and added to a bin containing the accumulated sum of these temperatures. This accumulated sum is presented on the display. The average value in millidegrees of the displayed data is presented on the screen in the top right corner while the number of one minute integrations is displayed at the top center position of the screen. When the observer decides he has integrated for long enough he terminates this mode with the STOP command.

The telescope is then driven to an off source position and the DICKE MODE BALANCE mode is again entered. If frequency switching is used, the NOISE POWER EQUALIZATION mode is then entered. In this mode only reference data are taken and this is used along with the last set of reference and calibration data taken while on source to calculate a set of 100 temperatures representing the difference between the off source and on source reference level. The average value in millidegrees of the difference appears at the top right position of the screen. A new set of data is presented every 5 seconds allowing the operator to equalize the levels and follow the progress. When the levels have been equalized to the satisfaction of the operator the mode is terminated with the STOP command (see Section 4.6).

With the telescope still off source the OFF SOURCE observing mode is entered. This mode is identical to that of the ON SOURCE observing mode. A set of 100 channels of integrated off source temperatures is built up over a period of time until the operator decides he has sufficient values for his final spectrum and pushes the STOP and then the SPEC push-buttons. This causes termination of the OFF SOURCE observing mode, calculation of the final spectral temperatures from the ONSO and OFSO temperatures and the presentation of the final spectrum on the display. The observer can then obtain a hard copy of his spectrum by pushing the PLOT push-button, thus plotting the displayed data on the digital plotter. A paper tape copy of the spectrum can be obtained by typing the command PSPC. This tape consists of an absolute section, which can be reloaded as a standard spectrum (see Section 1.10) or for averaging (see Section 1.11), and an optional (selected by console switch) section which can be listed on a teletype.

1.4 VARIATIONS ON BASIC SEQUENCE

It is not necessary that an observer adhere strictly to the sequence outlined in Section 1.3 above; circumstances might dictate that a different procedure would be better. Once the operator understands how the final spectrum is arrived at and how he has control over the data, he can form his own procedures. The final spectrum is calculated as per Equation 1.1.below

$$T_F = \frac{T_{ON}}{P} - \frac{T_{OFF}}{Q} \quad . \qquad (1.1)$$

---

*See COMMUTATE, see Section 1.6

In the above equation T_{ON} and T_{OFF} are the integrated temperatures derived from ONSO and OFSO respectively, P and Q are the respective number of integrations and T_F represents the final spectrum temperatures. It is best to think of T_{ON} and T_{OFF} occupying two buffers in the computer (see Section 1.5). These buffers are filled by the ONSO and OFSO observing modes and it is of no consequence (from program viewpoint) how one proceeds to collect data in these buffers. When either of the ONSO or OFSO modes is stopped by the STOP command the buffers are not changed and hence alternate ONSO's and OFSO's or any other arbitrary pattern can be used to collect the data in the T_{ON} and T_{OFF} buffers. The SPEC command provides a quick look facility in that the spectrum is calculated and displayed while any mode proceeds. This facility is useful in providing information to help the observer decide if he has sufficient data to terminate observations. If the observer wishes to terminate the observation and start a new source he can clear the T_{ON} and T_{OFF} buffers with the CLON and CLOF command respectively. While if he desires to save this information before clearing he can punch the contents of T_{ON} and T_{OFF} onto paper tape by utilizing the PONT and POFT commands. Subsequently these data can be loaded back into the T_{ON} and T_{OFF} buffers by use of the LONT and LOFT commands. This is extremely useful in cases where the source is setting but more integration is needed. The T_{OFF} buffer can also be loaded with a smoothed reference curve, produced off-line by the astronomer (see LOFT, Section 2.3).

A SPEC followed by a PLOT gives the observer a hard copy of the spectrum. Alternately the command SPCM (see Section 1.10) can be used to give a relative spectrum (current spectrum minus a reference spectrum). This may also be plotted.

1.5 INTERNAL BUFFERS

The computer program uses several buffers for the storage of data. For the convenience of program maintenance and for the enlightenment of users, these are listed below. The use and location of each is indicated. All buffers hold 100 quantities, in either integer of floating point format.

BUFFER	LOCATION	USE
INPUT	SCAN (SV 13) (INTEGER)	Holds 100 input voltages from 100 channels. Updated every 100 ms.
SIGNAL	SCAN (SV 07) (INTEGER)	Accumulates 100 signal voltages. Reset after 25 accumulations (DMBL, SETL), or 250 (500 in commutate mode) for ONSO, OFSO.
REFERENCE	SCAN (SV 09) (INTEGER)	Accumulates 100 reference voltages. Reset after 25 accumulations (NPEQ) or 250 (500 in commutate mode) for ONSO, OFSO.

BUFFER	LOCATION	USE
CALIBRATION	SCAN (SV 17) (INTEGER)	Accumulates 100 (calibration plus signal) voltages. Reset after 50 (100 in commutate mode) accumulations for ONSO and OFSO.
MAG. TAPE	SCAN (SV 29) (F.P.)	Filled at STOP during ONSO or OFSO with T_{ON} or T_{OFF} values for integration just ended. It is then output onto mag. tape.
NPEQ REFERENCE	SCAN (SV 34) (INTEGER)	Filled at STOP during ONSO or OFSO with contents of REFERENCE buffer.
NPEQ. CALIB.	SCAN (SV 73) (F.P.)	Filled at STOP during ONSO or OFSO with calculated values of (5 ESC-ESI) x (5 ESC + ESI) for preceding integration.
DISPLAY	SCAN (SV 38) (INTEGER)	General display buffer. Holds integer data to be displayed.
DISPLAY (QL)	SCAN (SV 66) (INTEGER)	Quick look SPEC and SPCM buffer. Holds integer data to be displayed.
ONSO	SCAN (SV 36) (F.P.)	Accumulates T_{ON} as calculated at each STOP during ONSO. Cleared by CLON. Can be initialized by LONT.
OFSO	SCAN (SV 11) (F.P.)	Accumulates T_{OFF} as calculated at each STOP during OFSO. Cleared by CLOF. Can be initialized by LOFT.
SPECTRUM	SAVE (SAR 1) (F.P.)	Filled with derived spectrum each time SPEC or SPCM command is invoked. In the case of SPCM, the relative spectrum is put in buffer. It is also filled with the average spectrum resulting from an AVSP operation. Note that the buffer is over-written when a LDRS command is executed.

BUFFER	LOCATION	USE
STAND.SPECT.	SAVE (SAR2) (F.P.)	Loaded with standard spectrum by LDRS command.
REF. SPECT.	SAVE (SAR3) (F.P.)	Loaded with standard spectrum by LDRS Command. Updated by SCRS command, at which time the contents of STAND.SPECT. are multiplied by a scale factor and are placed in this buffer. The contents of this buffer are used as the reference spectrum for SPCM operations.
AVERAGE SPEC.	SAVE (SAR4) (F.P.)	This buffer is used as an accumulator in an AVSP operation.
ECAL	SAVE (SAR5) (F.P.)	Loaded with the sum of 5 ESC - E1 (effectively the calibration voltage) over one integration, divided by 1250 (2500 for commutate mode), at every STOP during ONSO or OFSO.
ES1G	SAVE (SAR6) (F.P.)	Loaded with the sum of E1 (signal voltage) over one integration, divided by 1250 (2500 for commutate mode), at every STOP during ONSO or OFSO.
EREF	SAVE (SAR7) (F.P.)	Loaded with the sum of E2 (reference voltage) over one integration, divided by 1250 (2500 for commutate mode), at every STOP during ONSO or OFSO.
DISPLAY 1	DISPLAY (DB02) (INTEGER)	On entry to display processor, data to be displayed are loaded into this buffer.
DISPLAY 2	DISPLAY (DB04) (INTEGER)	Holds data from DISPLAY 1 buffer after the mean has been subtracted and scaling has taken place. The PLOT command plots the contents of this buffer.

1.6 COMMUTATION

The spectrometer can be operated in either the commutate or non-commutate mode. The commands COMM and NCOM respectively invoke these modes with the default option being the non-commutate mode. Commutation is accomplished by switching the frequencies to the mixers in banks two and three so that each 100 kHz (not 10 kHz*)bandwidth signal in the output has passed through each hardware channel an equal number of times. This is useful in eliminating hardware channel differences and makes possible the continued use of the spectrometer even with some channels inoperative.

When in the commutation mode, commutation takes place only during ONSO and OFSO. In order to ensure full commutation for calibration as well as signal and reference, the time spent on each was doubled and hence in the commutate mode one integration period (i.e. the time between successive display updates) requires 2 minutes as compared to the 1 minute required in the non-commutate mode.

1.7 TERMINATION OF OBSERVATION

The STOP command causes any particular mode of operation to be terminated and an idle condition to be entered. The operator must then take some further action to either continue observing or to terminate his observation. A normal termination would be a SPEC, a PLOT, and optionally PSPC to get a hard copy of the spectrum, followed by the commands to clear the desired buffers. If a data tape has been used (the observer has this option (see TAPE command)), an end of data mark should be placed on the tape with the MARK command at the end of the day's observing.

1.8 COORDINATE CONVERSION

Facilities exist in the line receiver program for certain coordinate transformations. If the indicated (current) equatorial coordinates corresponding to a given 1950.0 position are required, these can be obtained by using the PREC command. Included in the conversion from 1950.0 to indicate coordinates are pointing error corrections if these have been entered previously (using the PTNG command). It should be noted that the independent day numbers for the current date (or a recent date) must have been entered using the DNIN command before the PREC command can be used to precess forward from 1950.0.

Galactic coordinate conversions can similarly be made using the GALC command. Again, for a full conversion (galactic to indicated) independent day numbers and pointing constants must previously have been entered using the DNIN and PTNG commands.

By setting an appropriate console switch (see Section 2.2) one can have the computer list, at each ONSO command, the indicated coordinates corresponding to the coordinates last entered using a PREC or GALC command.

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*On 10 kHz the filters are not synchronously tuned.

1.9 DOPPLER CORRECTIONS

Automatic correction for the Doppler shifts introduced by the solar motion, the earth's annual and diurnal motion and any peculiar velocity of the source with respect to the Local Standard of Rest can be requested by using the DOPC command. Subsequently, the local oscillator frequency of the receiver will be adjusted every time the ONSO command is used. Correction will be made such that a line at the rest frequency specified in the FREQ command will be centered on channel 50 of the display if the velocity of the source (with respect to the Local Standard of Rest) equals that specified in the DOPC command. During execution of each ONSO command, a list of parameters involved in the Doppler correction (see Section 2.3) are listed. This listing may be suppressed by setting the appropriate console switch (see Section 2.2). The Doppler correction is derived from the equations given by MacRae and Westerhout, Lund Observatory, 1956. A solar motion of 20 km/sec with an apex (1900) $\alpha = 18^h\,00^m$, $\delta = 30°$ is used .

1.10 USE OF REFERENCE SPECTRUM

Two types of quick-look spectra can be displayed by the computer. The usual spectrum is that obtained using the SPEC command. (It is described in Section 1.4). Alternatively, one can display the difference between this spectrum and a standard (optionally scaled using the SCRS command) spectrum which has been entered previously from paper tape using the LDRS command. Such a spectrum is obtained by using the SPCM command, or can be produced off-line by the astronomer. Many uses of the feature could be envisioned, e.g. to determine line shifts from one region to another, to compare observations separated in time for variability, or to remove certain instrumental effects. The spectrum resulting from an SPCM command can be punched onto paper tape, using PSPC, or can be plotted.

1.11 AVERAGING ROUTINE

An "off-line" feature for averaging spectra has been built into the line receiver processor. Using this facility, paper tapes containing spectral data (which may have been produced by the SPEC, SPCM or AVSP commands) may be averaged with suitable weighting to obtain an average spectrum. The latter is then displayed and can be punched onto paper tape for later use. (N.B. All paper tapes containing spectral data have the same format and may be used at later times as standard spectra or for averaging purposes). For details of this operation, initiated by the AVSP command, see Section 2.3.

1.12 DIAGNOSTIC PROCEDURES

Several diagnostic capabilities have been built into the line receiver processor principally for engineering requirements, but certain features may be of interest to the astronomer.

a) Total power outputs to pen recorder. An analog voltage may be output to the pen recorder, by the setting of an appropriate console switch (see Section 2.2). This analog output can be either the average value of the voltage on the 100 signal channels, the average value on the 100 reference channels, or the average value of the voltage difference (signal-reference) . The analog output is updated every 0.2 second and has an effective time constant of 0.1 second, so the output is inherently noisy. If a longer time constant is required the signal must be routed through an external filter. Optionally, calibration signals appearing on the signal channel can be suppressed or can be allowed to appear. They appear for only 1 second out of 10 (2 out of 20 in commutate mode), so may be lost in the noise. All analog outputs are scaled exactly, i.e. one mv internally equals one mv output.

b) By setting an appropriate console switch (see Section 2.2), three diagnostic values will be typed out at the end of every ONSO or OFSO integration. These are ESIG, the average signal voltage over the 100 channels over the integration period just completed; EREF, the average reference voltage over the 100 channels; and ECAL, the average value of 5 ESC - E1 (the effective calibration voltage) over the 100 channels, all in units of millivolts.

c) After the completion of an ONSO or OFSO integration, the values of the signal voltages, reference voltages, or calibration voltage (5ESC - E1) for each of the 100 channels may be displayed by using the command ESIG, EREF and ECAL, respectively. In this case, the display unit is 0.1 millivolt.

1.13 FORMAT OF DATA TAPE

A data tape consists of a sequence of integration records followed by a file mark. Such a file corresponds to one observing session. (An observing session is started by positioning the data tape using PODT and is ended by putting an end-of-data mark on the tape, by MARK). An integration record is written at the end of every ONSO or OFSO integration and has the following format:

WORD NO.	CONTENTS
1	Integration code (1= ONSO, 2 = OFSO)
2	Integration number
3	Receiver configuration code, filled by RCVR
4	Operator flag, filled by FLAG
5, 6	Signal frequency (MHz), in floating point format
7, 8	Source peculiar velocity (km/s), in floating point format
10, 11, 12, 13, 14	Spare

15, 16, 17	Source name, entered by NAME, in TASCII.
18	Polarizer angle (QV format)
19	Azimuth (QV format)
20	Zenith Angle (QV format)
21	Declination (QV format)
22	Hour Angle (QV format)
23	Right Ascension (QV format)
24	Local Sidereal Time (QV format)
25	Eastern Standard Time (QV format)
26	Console switch setting
27-226	Temperatures T_1 - T_{99} in floating point format.

All words are 24 bits in length represented by 4 characters on the tape. Unless otherwise specified, words are integers in 2's complement form. QV format is a binary fraction of a circle, scaled to the right of the sign bit. Floating point format requires two words. Details can be obtained from the SEL reference manual.

The tape is seven track, recorded in IBM compatible format. The density is low (200 bpi), odd parity.

The MARK command writes an end-of-file followed by a record consisting of three −1 words. The PODT command finds the first such record on the tape and back-spaces over it.

1.14 RESTART AND COMPUTER DIAGNOSTICS

There are three ways in which the computer may be restarted after a failure.

a) The first method, necessary in the case of catastrophic failure – i.e., the program has been overwritten, is the normal bootstrap procedure used to initially load the program.

i) Place the line receiver system tape on a transport with selector switch at 0. Position it at the load point (POWER, FWD, REMOTE).

ii) Turn program protect key fully counter-clockwise.

iii) Put 3 in T register by depressing switches 22, 23.

iv) Enter into program counter.

v) Clear T register.

vi) Ensure that command teletype is ON-LINE.

vii) Push START twice.

b) If the failure has not destroyed any of the program, the computer may be restarted as follows:

i) HALT, CLEAR computer

ii) Enter 140_8 into the program counter by following steps *iii–v* in a) above, but using switches 17, 18 instead of 22, 23.

iii) Ensure that all switches are off.

iv) Push START twice.

If any of the following commands had been entered before the failure, they must now be re-entered:

/DNIN
/DOPC
/COMM

The calibration temperature will be set to 10.0°. If this is not desired, the calibration drive should be driven away from its current position, and then to the value desired. The ONSO and OFSO buffers are cleared. This restart differs very little from a complete reload.

NOTE: If the display does not come on with a scale factor and integration number, reset it using the RESET DISPLAY button.

c) If the failure has not destroyed the program and the contents of the ONSO and OFSO buffers are to be preserved, restart as follows:

i) HALT, CLEAR computer

ii) Set switch 0 on.

iii) Enter 140_8 into the program counter by following steps *iii–v* in a) above, but using switches 17, 18 instead of 22, 23.

iv) Push START twice.

v) Turn switch 0 off

If /COMM had been entered before the failure, it must now be re-entered. The calibration temperature will be unaffected. The restart will be indicated by the message RESTARTED.

d) Computer diagnostics. When the computer program is running, the contents of any core location can be displayed in the B accumulator by setting the address of the core location on the control switches. This turns off the CRT display but does not affect program operation. Also displayed are:

A Accumulator	–	Location of instruction last interrupted by QVAL processor.
Index Reg. 1	–	Location of instruction last interrupted by Command Language processor.
Index Reg. 3	–	Location of instruction last interrupted by SCAN processor.

1.15 CHECK LIST OF PANEL SWITCH SETTINGS

Continuum Observations

Spectrometer Console

Calibration control switch . . . . MANUAL (or COMPUTER if data acquisition system is being used)

Computer switch . . . . CONTINUUM

Calibration and balance functions remain on this panel. Use the standard receiver console for setting the synchronous detector and filters.

Spectrometer Rack

Frequency switching . . . . OFF

All other switches not applicable.

H.P. Synthesizer

Needed only for locked LO system..

Operation switch . . . . REMOTE

Interface . . . . ON and connected via J7, J8, J9 at rear of synthesizer

2.8-cm Paramp Rack

Ferrite switch driver — Function switch	DICKE
System mode panel – rate switch	CONSOLE
Local oscillator panel switch (Dual 28 V VR supply)	ON
Local oscillator control panel	
Unlocked operation – servo loop	OPEN
Using calibration table	set tuning meter with TUNING control and switch to desired frequency.
Locked operation	As above, then close SERVO LOOP. LEVEL indicated by meter should be unaffected by tuning inside the lock range.

Line Observations

Console

Calibration control switch	COMPUTER
Computer switch	SPECTROMETER
Spectrometer command panel	see handbook for operating procedure.
Bandwidth select switch	select 100 kHz or 10 kHz filters

Spectrometer Rack

Commutator panel switch	COMPUTER*
Multiplexer panel – set switches* to	COMPUTER FREE RUNNING HI RATE SINGLE SCAN
Mode select panel bandwidth switch	CONSOLE*
oscillators	ON*
frequency switching	OFF†
Logic panel	COMPUTER (all others down)*

*These not normally disturbed except for testing.

†When frequency switching is desired instead of load switching, turn this ON.

HP Synthesizer

Remote (programmed) operation	Interface ON and connected via J7, J8, J9 at rear.

2.8-cm Paramp Rack

Ferrite switch driver – function switch	DICKE*
– rate switch	CONSOLE
System mode panel – Ref W/G	COLD LOAD
Local oscillator control	Dual 28V VR supply ON, tune to desired current on meter indicator while Servo Loop OPEN, using calibration table on panel. Close Servo Loop and test for LOCK to synthesizer. Power meter level should be unaffected by TUNING inside lock range.

Computer

Custom buffer	Exchange connectors channel 8 and 9 unit 74 designated CONTROL for pair designated LINE RECEIVER.

1.16 LOCKING LO1 TO FREQUENCY SYNTHESIZER

Experience with operating the LO1 frequency locking system led to a simpler procedure that worked every time during the June 1971 trials. The original procedure will produce a lock and perhaps give more confidence that the correct frequency has been locked in, but we eventually used the new procedure as a check on the accuracy of the LO1 wavemeter.

The procedure is as follows:

1. Set the servo loop control to open loop.
2. Set the tuning current for the required LO1 frequency (equals the RF frequency minus 114.5 MHz) using the tuning control and the curve of the LO1 frequency versus open loop tuning current.
3. Set the synthesizer frequency to $\frac{\text{RF frequency} - 114.5}{228}$ MHz
4. Set SERVO LOOP CONTROL to CLOSED LOOP.

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*When frequency switching is desired instead of load switching put Function Switch to ANT.

5. Check, by adjusting the tuning control, that lock has been achieved. If it has, the LO1 monitor will remain quite steady as the error current varies over a large range (a total swing of about 60μA or more). Practice with the 'feel' of this operation quickly provides confidence in the system.

NOTE: The error current should swing roughly symmetrically around zero, although this is not critical.

There is a bias adjustment accessible in the side of the LO1 box in the receiver package. This is adjusted in quarter turn steps and the lock range checked by varying the tuning until a fairly symmetrical error swing is obtained.

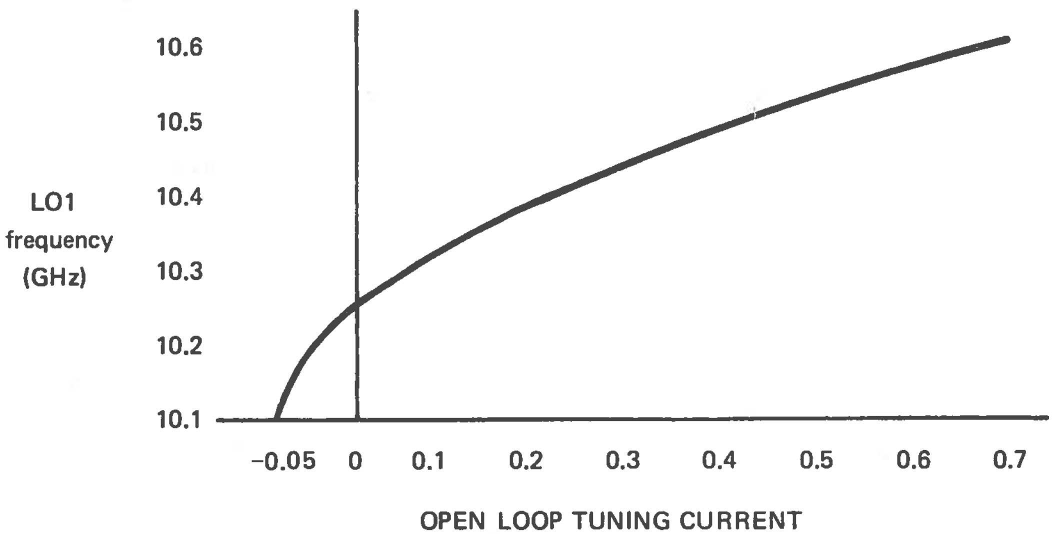


PLATE 1.1 Spectrometer control panel

II COMMAND LANGUAGE

2.0 INTRODUCTION

This section provides information on computer control of the line receiver. A description of the console and teletype commands is presented. The most often used commands are implemented via a set of push-buttons on the spectrometer control console. Two of these push-button implemented commands require arguments and these are provided by means of thumbwheel switches. The push-button commands are backed up by a corresponding set of teletype entered commands. Additional teletype commands are provided for functions which are infrequently used. In Section 2.1, commands and brief descriptions are listed in classifications according to function. In Section 2.2, the assignment of console switches is given, while in Section 2.3, detailed descriptions of each command are given. Where a command may be entered both via the teletype and via the push-buttons, the console label of the push-button is given in square brackets [ ]. Commands requiring arguments have these indicated by xx and/or yy. Note that for arguments including decimal points, the number of characters following the decimal point *must* be given and at least one character must always precede the decimal point. Arguments which are optional are given in round brackets ( ).

2.1 COMMANDS GROUPED BY FUNCTIONAL CLASSIFICATION

* indicates that argument(s) for push-button commands are entered via thumbwheel switches.

Classification	Teletype Mnemonic [and label]	Arguments	Function
A. Display Operations			
	BASE	(xx,yy,N.NN)	Fit sine curve to display, using channels 00 to xx and yy to 99, and remove the fitted curve from the display.
	EXPD [EXPAND*]	xx, yy	Display only channel xx to yy inclusive.
	PDBF		Punch the contents of the current display buffer onto paper tape.
	PLOT		Plot contents of display or plotter.
	RMSN	(xx, yy)	Calculate RMS noise on display and print parameters. Channels xx + 1 to yy − 1 (inclusive) are ignored.
	RSET [RESET DISPLAY]		Reset display to its previous state.
	S.F. [SCALE FACTOR*]	x	Change scale of display by using basic scale factor defined by index x.
	SCAL	xxxx	Update value of basic scale factor defined by index = 9 to xxxx.
	ZERD [ZERO DISPLAY]		Zero the display.
B. Commands for Program Maintenance			
	KEIN	$'xx, x_1, x_2 \ldots x_n$	Enter octal words $x_1 \ldots x_n$ into core memory starting at 'xx.
	LIST	'xx, yy	List contents of core locations 'xx to 'yy.
C. Receiver Test Operations			
	ECAL		Display calibration voltages.
	EREF		Display reference voltages.
	ESIG		Display signal voltages.
	FREQ	x.xxx(,y.yyy)	Set up line frequency x.xxx MHz and reference (first LO switching) y.yyy MHz.
	ICAL	(x)	Calibrate display and plotter with zero level (x = 0) or ±4 volts (x ≠ 0).
	SYNT		Enter frequency synthesizer setting.
	ZERD [ZERO DISPLAY]		Zero the display.

Classification	Teletype Mnemonic [and label]	Arguments	Function
D. Commands Used During Observations			
a) Initial set-up			
	CALT	(x,yy.yy)	Update value of calibration temperature corresponding to index = x to yy.yy, or list cal. temp. being used currently (no arguments).
	COMM		Set system to commutate mode.
	DNIN		Input independent day numbers, on paper tape, for precession calculations.
	DOPC	yyyy mm dd (vv.v)	Set up Doppler correction routine for day = dd, month = mm, year = yyyy and peculiar velocity = vv.v km/s (wrt L.S.R.).
	NCOM		Set system to non-commutate mode.
	PTNG		Enter telescope pointing errors on teletype.
	TAPE	(x)	Turn data tape (magnetic tape) on (x = 0 or blank) or turn data tape off ($x \neq 0$).
b) Entry of Constants or Flags			
	CALT	(x,yy.yy)	Update value of calibration temperature corresponding to index = x to yy.yy, or list calibration temperature being used currently (no arguments).
	FLAG	xxxx	Put integer xxxx into flag location of header written on data (magnetic) tape.
	NAME		Enter name of source, to be put in data tape header.
	RCVR	xxxx	Enter receiver code (= integer xxxx) into data tape header.
	SCAL	xxxx	Update value of basic scale factor (for display) defined by index = 9 to xxxx.

Classification	Teletype Mnemonic [and label]	Arguments	Function
	SCRS	x.xxx	Scale standard spectrum by x.xxx to obtain a new reference spectrum.
c) Commands Affecting Observing Mode			
	CLOF [CLOF]		Clear off-source buffer.
	CLON [CLON]		Clear on-source buffer.
	DMBL [DMBL]		Commence Dicke-mode balance operation.
	NPEQ [NPEQ]		Commence noise power equalization operation.
	OFSO [OFSO]		Commence off-source integration.
	ONSO [ONSO]		Commence on-source integration.
	PLOT [PLOT]		Plot contents of display on plotter.
	PSPC		Punch spectrum onto paper tape.
	SETL [SETL]		Commence set level operation.
	SPEC [SPEC]		Display current spectrum.
	STOP	(x)	Stop current operation now ($x < 0$ or blank) or stop after the xth integration ($x > 0$).
d) Coordinate Conversions			
	GALC	LL.LLL, BB.BBB	Convert the galactic coordinates L,B to indicated equatorial coordinates.
	PREC	HH MM SS.S, DD MM SS.S	Precess the 1950.0 position given by the two arguments (α and δ). to current indicated α, δ.
e) Data Tape Commands			
	FLAG	XXXX	Put integer XXXX into flag location of header written on data (magnetic) tape.
	MARK		Write end-of-data mark on data tape.
	NAME		Enter name of source, to be put in data tape header.

Classification	Teletype Mnemonic [and label]	Arguments	Function
	PODT		Position data tape to first end-of-data mark on tape.
	RCVR	XXXX	Enter receiver code (= integer XXXX) into data tape header.
	TAPE	(X)	Turn data tape facility on (X = 0 or blank) or turn data tape off (X ≠ 0).
f) Paper Tape Commands			
	AVSP		Average series of spectra which are on paper tape.
	LDRS	(x)	Load a paper-tape standard spectrum (x = 0 or blank for absolute format, x ≠ 0 for teletype format).
	LOFT	(x)	Load off-source paper tape (x = 0 or blank for absolute format, x ≠ 0 for teletype format).
	LONT		Load on-source paper tape.
	PDBF		Punch the contents of the current display buffer onto paper tape.
	POFT		Punch off-source paper tape.
	PONT		Punch on-source paper tape.
	PSPC		Punch spectrum onto paper tape.

2.2 CONSOLE SWITCH SETTINGS

The console switches above the pen recorder can be used to select certain options in the processing. The functions of these switches are indicated below:

Switch		Function
0	ON	List Doppler correction parameters during execution of every ONSO command.
	OFF	No listing of Doppler parameters.
1	ON	List current values of desired indicated α and δ, during execution of every ONSO command, based on last 1950.0 equatorial position entered by PREC or last galactic position entered by GALC.
	OFF	No listing of desired coordinates.
2	ON	List average values of signal, reference and calibration voltage at end of every ONSO or OFSO integration. Units are millivolts and refer to the average sampled value per channel of E1, E2 and 5 ESC–E1 respectively.
	OFF	No receiver diagnostics.
3	ON	Include calibration deflections in any voltage plots done on the pen recorder.
	OFF	No calibration data are output to the pen recorder. During calibrations, the last signal voltage (or signal minus reference) is held.
4	ON	Output the mean sampled signal voltage to the pen recorder every 0.2 second.
	OFF	No signal voltage will be output to the recorder.
5	ON	Output the mean sampled reference voltage to the pen recorder every 0.2 second.
	OFF	No reference voltage will be output to the recorder.

Switch		Function
4 and 5	Both ON	Output the mean sampled (signal-reference) voltage to the pen recorder every 0.2 second.
6	ON	In operations which punch spectra onto paper tape, suppress the second portion of the tape which can be listed on a teletype.
	OFF	Punch two-part paper tapes in spectrum dumps.
23		Change state to obtain a listing of start-up procedures, console switch assignment and basic operating assistance.

2.3 DESCRIPTION OF COMMANDS

Notes † Denotes commands which are only accepted when the processor is in a STOP state.

Certain commands require real time I/O and can only operate when a special service routine used for this task is free. This is indicated in the comments of the relevant commands.

Command	Description
†AVSP	Average series of spectra which are on paper tape as absolute modules (created by PSPC following SPEC or SPCM, or by a previous AVSP). If the service routine is busy, no action is taken. Otherwise, the weight of the first spectrum is requested. The weight is typed in as an integer and the first spectrum is read by the paper tape reader. (If the paper tape was not a proper SPEC, SPCM, or AVSP tape, a diagnostic message will be typed and action stopped). The weight of the next spectrum is then requested and the process continues. To terminate the series, a weight of 0 or just a carriage return is typed. The overall (weighted) spectrum is then displayed, placed in the SPECTRUM buffer, and punched onto paper tape. If console switch 6 is "off", a teletype portion is also produced.

Command	Description

†BASE (xx,yy, N.NN)

Calculate the 'reflection standing wave' curve of the type $y = A + B\sin[Nw(t-c)]$ best fitting the display, using the data in channels o to xx and yy to 99 only. If xx and yy are omitted, all channels are used. If xx and yy are such that less than three channels are used, no action is taken. The display is updated by the removal of the above curve and A, B and C are typed out. A and B are in display units and C is a channel number. (The quantity t is the channel number and $w = 4\pi\ \Delta\nu\ F/C$ where $\Delta\nu$ is the channel bandwidth, F is the antenna focal length and C is the velocity of light). The value of N can be defaulted, giving N = 1.00.

†CALT (X,YY.YY)

a) Update value of calibration temperature for index = X ($1 < X < 5$) to YY.YY degrees or

b) Type out value of calibration temperature currently in use (no arguments).

If X lies outside range given above, an error will result. Note that two digits past the decimal point are required for the temperature. In both cases, the message X CAL TEMP = YY.YY is typed. For case b) X = 0 and the current temperature is listed. The initial calibration temperature table is:

Index	*Temp.*	
1	0.1	
2	1.0	← These two wired to lower and upper limits on calibration attenuator
3	2.5	
4	5.0	
5	10.0	←

In the absence of a code from the console panel (zero volts) the program automatically uses 10° for calibration. With the code voltages on the initial code, regardless of the setting of the switches, the calibration code will be 2 (i.e., 1° in the table). To properly set the calibration code be sure to select *calibration* mode and press the level switch *toward*

Command	Description
	the level desired (1° or 10°). This will set a relay which will transmit the correct code. If the table is updated, for instance by typing in CALT 5,20.00, the old value will be used until the code is switched from 5 to 2 and returned to 5 again. It is only when the code is changed that the computer consults the table for new values. It is obvious that the switch should not be moved during an integration.
†CLOF [CLOF]	Clear the off-source buffer (OFSO) and display zeroed buffer. This destroys all off-source data previously acquired.
†CLON [CLON]	Clear the on-source buffer (ONSO) and display zeroed buffer. This destroys all on-source data previously acquired.
†COMM	Set system to commutate mode. The message COMMUTATOR ON will be typed. Note that commutation is only done in the ONSO and OFSO modes.
†DMBL [DMBL]	Commence Dicke-mode balance operation (5 second integrations of signal voltage, E1, minus the reference voltage, E2). No commutation is done. The display unit is 80 microvolts (i.e., the sum of 25 samples of [(E1 - E2)/2] millivolts per channel).
†DNIN	Command to paper tape reader to read tape containing the independent day number for the precession calculations. The format of the paper tape is YYYY MM DD f g G h H i (CR) where YYYY, MM, DD are numbers giving the year, month and day. The last six quantities

Command	Description
	are the independent day numbers, exactly as listed in the A. Ephemeris and N. Almanac for the corresponding date. The number of digits following a decimal point must be exactly the same as given there. For example, a tape for April 10, 1971 would read: 1971 04 10 1.4422 12.101 21 23 42 18.988 16 35 42 -7.683 (CR)
†DOPC YYYY MM DD (VV.V)	Invoke Doppler correction mode and set up parameters for year = YYYY, month = MM, day = DD and peculiar velocity (wrt L.S.R.) = VV.V km/s. If VV.V is not given, a peculiar velocity of zero is assumed. The corrections will be so made that a line having the rest frequency given in a FREQ command lies in channel 50 if the peculiar velocity of the source equals VV.V km/s. During the execution of every subsequent ONSO command, the Doppler corrections are made and the following data are (optionally) listed: a) The component of the observer's velocity wrt the L.S.R. in the direction towards the source (measured + towards the source). This includes the earth's annual and diurnal motion and the solar motion. b) The source velocity wrt the L.S.R. = the value of VV.V entered with DOPC. c) The rest signal frequency as entered by FREQ and the current Doppler correction ($F = F_0$ + correction)

Command	Description
	d) The rest reference frequency as entered by FREQ and the current Doppler correction.
	e) The 1950.0 equatorial coordinates at which the telescope is currently pointing (as deduced from the indicated coordinates using the precession and pointing constants entered by DNIN and PTNG).
	f) The current indicated Az and ZA of the telescope.
	g) The time in days since 1950.0
	This listing is only obtained if console switch 0 is set to "ON". The Doppler corrections are still made. If no DOPC command has been issued prior to an ONSO command, the message "NO DOPPLER CORRECTION MADE" is typed. Note: The program will detect the passing of a 24 boundary of EST and will automatically increment the number of days since 1950.0 (initially derived from the date given in the DOPC command). For extended observing sessions, one should ,however ,check this by monitoring quantity g) in the above listing.
	The signal frequency (corrected) and the source velocity (VV.V) are also placed in the header of the data record written onto the data (magnetic) tape.
†ECAL	Display 100 mean calibration voltages (actually 5ESC - E1) recording during the previous integration. The display unit is 0.1 millivolt (mean sampled value of voltage per channel over last integration).

Command	Description
†EREF	Display 100 mean reference voltages (E2) recorded during the previous integration. The display unit is 0.1 millivolt (mean sampled voltage per channel over last integration).
†ESIG	Display 100 mean signal voltages (E1) recorded during the previous integration. The display unit is 0.1 millivolt (mean sampled voltage per channel over last integration).
EXPD [EXPAND*] XX,YY	Display channels XX to YY inclusive. If XX = YY, no action is taken. If XX > YY, channels YY to XX inclusive are displayed.
FLAG XXXX	Put integer XXXX into flag location (fourth word) of header of the data record written on the data tape (see Section 1.3).
†FREQ X.XXX(,Y.YYY)	Set line rest frequency to X.XXX MHz. Optionally, if the computer is to do first LO frequency switching, the reference rest frequency, Y.YYY MHz, may be given. Note that three digits following the decimal point must be entered unless fractional part is = .000. Then .0 is sufficient. The frequency synthesizer is immediately set to the proper signal frequency. The message "SIGNAL PREQ = X.XXX 1 CHANNEL = Z KM/S" is typed out. The value Z gives the channel separation in km/s. If a reference frequency has been entered, the message "REF FREQ = Y.YYY" is also typed, and the computer is set to the first LO frequency switching mode. In general, this mode is not advocated on technical grounds.
†GALC LL.LLL, BB.BBB	Convert the galactic coordinates L,B to indicated equatorial coordinates. Note that three digits after the decimal place must be given (L and B are in degrees). The indicated α and δ are typed out, derived using pointing errors and precession constants entered via PTNG and DNIN. If these were not entered, "NO PTNG" and/or "NO PREC" will be typed, and the conversion will be made neglecting pointing errors and/or precession. If console switch 1 is "ON", and no subsequent GALC or PREC commands are issued, at each subsequent ONSO operation the current indicated equatorial coordinates corresponding to L and B are typed out.

Command	Description
ICAL (X)	Calibrate the display and plotter with a zero volt level (X = 0 or blank) and ±4 volts (on alternate channels) if X ≠ 0. In the latter case, a +4 volt level is output to the plotter. Note that plotter signals consist of output voltage only. No seek pulses are issued. Note that a +4 volt output to the display corresponds to 2000 display units.
KEIN 'XX,X_1(,X_2. . . X_N)	Enter octal words $X_1 \ldots X_N$ into memory starting at location XX. N *must* be in the range $1 < N < 18$. Note that the octal symbol must precede the address. Blanks or commas may separate arguments.
†LDRS (X)	Load a paper-tape standard spectrum (if X = 0 or blank, in form of an absolute module produced by PSPC or AVSP; otherwise (X ≠ O) in the teletype format described under PSPC; temperatures must have the format XX.XXXX.). If the service routine is busy, no action is taken. If the paper tape is not a spectrum tape or is in incorrect teletype format, a diagnostic message is typed and action is terminated. The SPECTRUM buffer is over-written and the data are placed in both the STAND.SPECT. and REF.SPECT. buffers.
LIST 'XX,YY	List (in octal format) the contents of core location 'XX to 'YY inclusive. The location YY must be > XX, or no operation will result. The number of locations listed will always be a multiple of 6 so that locations beyond 'YY may be listed. If the service routine is busy, no action is taken. Note that the octal symbol *must* precede the first address.
†LOFT (X)	Load off-source paper tape (if X = O or blank absolute module produced by POFT; otherwise (X ≠ O) a tape in the teletype format described under PSPC. Temperatures must have the format XX.XXXX.). If the service routine is busy, no action is taken. If the paper tape read by the reader is not an off-course tape or is in incorrect teletype format, a diagnostic message is typed and action is terminated. The OFSO buffer is loaded and the off-source integration number is set to that existing when the tape was produced. (If the tape was in teletype format the integration number is set = 1).

Command	Description
†LONT	Load on-source paper tape (absolute module produced by PONT). If the service routine is busy, no action is taken. If the paper tape read by the reader is not an on-source tape, a diagnostic message is typed and action is terminated. The ONSO buffer is loaded and the on-source integration number is set to that existing when the tape was punched.
MARK	Write end-of-data mark on data tape, preceded by an end-of-file mark. This is ignored if data tape has been turned off by TAPE command.
NAME	Causes program to request entry of source name by message "TYPE IN SOURCE NAME". Any 12 character (or less) name is typed in followed by a carriage return. The name is placed in the data (magnetic) tape header written with each record (see Section 1.13).
†NCOM	Set system to non-commutate mode. The message "COMMUTATOR OFF" will be typed. This is the system default when initially loaded.
†NPEQ [NPEQ]	Commence noise power equalization operation (derive value of current mean reference voltage, E2, minus mean reference voltage, E2', from previous ONSO or OFSO integration, based on a current 5 second integration). No commutation is done (but possibility of commutation in derivation of E2' is noted from current commutate status). The display unit is millidegrees, based on the calibration data from the previous ONSO or OFSO integration.
†OFSO [OFSO]	Commence off-source integration. Integrations of one (two in case of commutate mode) minute duration are made. During this time, 250 (500 in commutate) samples each of the signal voltage, E1, and reference voltage, E2, are taken along with 50 (100 in commutate) samples of the calibration voltage, ESC.

The quantity defined by

$$T = T_{cal} \frac{(\Sigma E1 - \Sigma E2)(\Sigma E1 + \Sigma E2)}{(5\ \Sigma ESC - \Sigma E1)(5\ \Sigma ESC + \Sigma E1)}$$

is calculated at the end of each integration and added into the OFSO buffer. The average value T (sum divided by number of integrations) is displayed in units of millidegrees.

Command	Description
†ONSO [ONSO]	Commence on-source integration. The same comments as for OFSO apply except that the ONSO buffer is affected.
†PDBF	Punch the contents of the current display buffer (DISPLAY or DISPLAY (QL)) onto paper tape in teletype format. The format is the same as that for /PSPC with the individual channel readings in the form of integral display units. No action is taken if the service routine is busy.
PLOT [PLOT]	Plot contents of display (buffer DISPLAY 2). If service routine is busy, no action is taken.
PODT	Position data tape to first end-of-data mark on tape. If service routine is busy, no action is taken. Upon recognizing an end-of-data mark (record of three words $= -1$, tested by finding sum of three word record $= -3$), the tape is positioned ahead of the mark.
†POFT	Punch off-source paper tape. The contents of the OFSO buffer and the off-source integration number are punched as an absolute module to be reloaded later using LOFT. If the service routine is busy, no action is taken.
†PONT	Punch on-source paper tape. The contents of the ONSO buffer and the on-source integration number are punched as an absolute module to be reloaded later using LONT. If the service routine is busy, no action is taken.
†PREC HH MM SS.S DD MM SS.S	Precess the 1950.0 position given by the two arguments (α_0 and δ_0) to current indicated α and δ. Note that one digit after the decimal point is needed in the seconds of α and in the arc seconds of δ. The indicated α and δ are typed out, derived using pointing errors and precession constants entered via PTNG and DNIN. If these were not entered, "NO PTNG" and/or "NO PREC" will be typed and the conversion will be made neglecting pointing errors and/or precession. If console switch 1 is ON, and no subsequent GALC or PREC commands are issued, at each subsequent ONSO operation the current indicated α and δ corresponding to α_0 and δ_0 are typed out.

Command	Description
†PSPC	Punch contents of SPECTRUM buffer onto paper tape in absolute load format and, optionally, followed by a portion in a format that can be listed on a teletype. This allows one to get a hard copy of a spectrum and to get a load version that can be used as a standard spectrum (see LDRS) or for averaging purposes (see AVSP). If console switch 6 is OFF, a two-part tape is produced, otherwise the teletype portion is suppressed. The format of the latter is

Channel No.	Temp.	Channel No.	Temp.
0	T_0	50	T_{50}
1	T_1	51	T_{51}
.			
.			
.			
49	T_{49}	99	T_{99}

If the service routine is busy, the command PSPC is ignored.

Command	Description
†PTNG	Causes program to request entry of telescope pointing errors on teletype. A message requesting the input of the following quantities is typed.

Quantity	*Format*
ΔHA	SXX.X seconds
ΔDEC	SXX arc secs
ΔAz	SXX arc secs
ΔZA	SXX arc secs
CE (sidereal clock error)	SXX.X seconds

S denotes sign (if needed). Sign of errors are given by $\Delta Q = Q(\text{true}) - Q(\text{indicated})$. CE is positive if clock is fast. Note that format must be followed. These quantities are entered on one line (separated by spaces) and the line is terminated by a carriage return.

If other commands use pointing constants (PREC, GALC) and none have been entered using PTNG, the message NO PTNG will be typed, indicating that coordinate conversion has taken place assuming zero pointing errors.

Command	Description
RCVR XXXX	Place integer XXXX into receiver configuration position in data (magnetic) tape header (see Section 1.13). This location can be used for any purpose by the observer, of course, and is not really restricted to a receiver code.
†RMSN (XX,YY)	Calculate r.m.s. deviation from the best straight line fitted to the display, excluding channels XX to YY (exclusive). If no arguments or only one argument is given, all channels are used. If XX > YY, incorrect operation will result. The display is updated by removing the best-fitting straight line so derived. The parameters A and B of the straight line, defined by $$\text{baseline} = A + Bi$$ where i is the channel number, and the r.m.s. deviations are listed on the teletype. Units are display units.
RSET [RESET DISPLAY]	Reset display by removing the effects of any EXPD [EXPAND], or ZERD [ZERO DISPLAY] operation. Also used to reset the display to its previous state after an SPCM or SPEC (quick-look) operation.
S.F. [SCALE FACTOR*] X	Change scale of display by using the basic scale factor defined by index X. Basic scale factors versus index are given below. One must note that the actual scale factor used will be the basic factor divided by the integration number.

Index	Basic factor (display units/cm)
0	50
1	100
2	250
3	500
4	1000
5	2500
6	5000
7	25000
8	50000
9	variable

Command	Description
	The value of the basic scale factor for index = 9 is initially (upon loading program) 500000 but can be set to any value using the SCAL command. Initially (upon loading program) a basic scale factor of 500 is used. Note that if a negative argument of $X > 9$ is entered, incorrect operation will result.
SCAL XXXX	Insert new value of basic scale factor to be associated with index = 9. The units are display units/cm. Note: only multiples or sub-multiples of 500 are valid factors. Hence the value used by the machine will be 500/INT (500/XXXX) if XXXX < 500 or 500 x INT (XXXX/500) if XXXX > 500. A value of XXXX = 0 or > 8388607 (the absolute value is used) will lead to errors.
†SCRS X.XXX	Define a new reference spectrum equal to the standard spectrum (in buffer STAND.SPECT.) multiplied by the scale factor X.XXX. Note that three digits after the decimal point must be given (unless X.XXX = X.000 in which case X.0 will do). The new reference spectrum is placed in buffer REF.SPECT. The message "REF.SPECTRUM SCALED BY X.XXX" is typed. Note that the standard spectrum is unaffected.
†SETL [SETL]	Commence set level operation. The signal voltage, E1, is summed during a 5-second integration and the mean value is displayed in units of 80 micro-volts (i.e., the displayed quantity is the sum of 25 samples of [E1/2] millivolts per channel). No commutation is done.
SPEC [SPEC]	Display current spectrum. The means of the current contents of the ONSO and OFSO buffers are each taken, using the respective integration numbers, and the difference is displayed. The display unit is millidegrees. The SPECTRUM buffer is also updated. If less than 5 seconds remains before an integration will be completed, this command will be ignored and the message "TRY AGAIN" will be typed. Also, the command will be ignored if some observational operation other than OFSO or ONSO is in progress. SPEC is a quick-look operation, so the data which were being displayed when SPEC was invoked can be returned to the display by RSET

Command	Description
	[RESET DISPLAY]. If the previous display was SPCM, the display must be reset and SPEC issued again if a display of SPEC is desired. A hard copy of the spectrum can be obtained by PLOT and/or PSPC (with switch 6 off).
SPCM	Display relative spectrum (current spectrum minus the reference spectrum). This command operates in exactly the same fashion as does SPEC, except that the reference spectrum is subtracted before the SPECTRUM buffer is loaded and the data are displayed. If the previously displayed datum was SPEC, the display must be reset and SPCM issued again.
STOP (X)	Stop current operation now ($X < 0$ or blank), or stop after the Xth integration if $X > 0$. The second form of this command applies only to ONSO or OFSO operations. If a STOP X has been issued, when either X ONSO or X OFSO integrations have been made, an automatic stop will be issued and the teletype bell will ring. The command is then cancelled and must be reissued if it is required.
SYNT	Enter frequency synthesizer setting. This command triggers the request TYPE IN FREQ: . The 10 digit frequency (in units of .01 Hz) is then entered followed by a carriage return. Note that exactly ten digits must be entered. The synthesizer is then set to this frequency. If the service routine is busy, no action is taken.
TAPE (X)	Turn data tape facility onf ($X = 0$ or blank) or turn data tape facility of ($X \neq 0$). Initially, the data tape facility will be on and at the end of every integration, data will be dumped onto magnetic tape.
ZERD [ZERO DISPLAY]	Zero the display buffer (DISPLAY 2) and then display the zero level for calibration purposes. Note: scale factor, average value and mode mnemonic are turned off. Return to normal operation by using RSET [RESET DISPLAY].

III DESCRIPTION OF THE SPECTROMETER

3.1 OBSERVATIONS OF NOISE SPECTRA

The observed source spectrum is defined by a set of output voltages, representing the noise power received at points spaced uniformly along the frequency axis. The input power spectrum delivered by the antenna to the receiver is simply expressed in terms of the equivalent black body temperature and it can be related to the output by a gain function

$$E(f) = G(f) \cdot T(f)$$

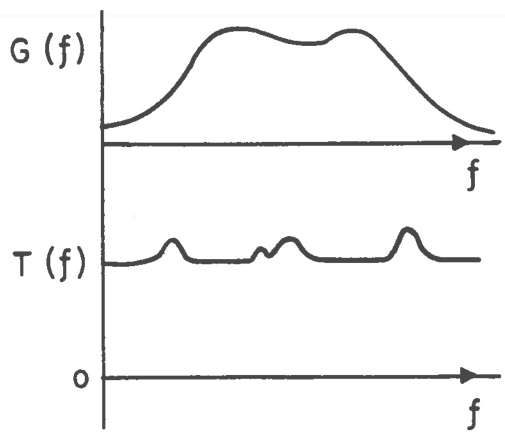


Figure 3.1 Input/output relations

Assuming we can separate $T(f)$ into receiver and source noise, then

$$E = G(T_r + T_s)$$

where all terms are functions of frequency. In an ideal receiver with absolutely stable gain, the function G would be constant with time. Errors in observing should be caused only by statistical variations in E (thermal noise at the power detector output). These are inversely proportional to the square root of the input bandwidth and of the integration time. Figure 3.2 shows the relationship for a 100°K system between bandwidth and integration time. The dotted lines enclose the area where spectral observations are generally made. To evaluate G, calibration of the receiver is required at time intervals short enough to eliminate significant gain changes. If we can add a known temperature, T_{cal}, small enough not to affect the linearity of the system, a new output set of voltages

$$E_{cal} = G(T_r + T_s + T_{cal})$$

will be obtained.

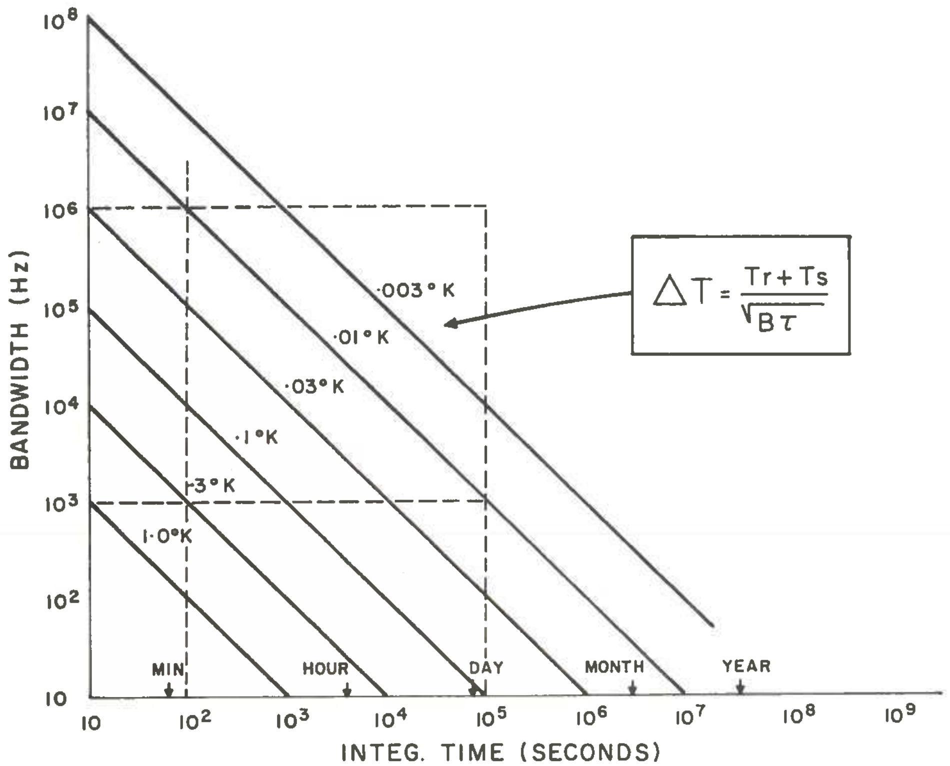


Fig. 3.2 Minimum detectable power in a 100°K system

If we combine this with the first expression we obtain

$$T_r + T_s = \frac{E}{E_{cal} - E} T_{cal}$$

It is easy to show that this result has a statistical error of

$$2\left(1 + \frac{T_r + T_s}{T_{cal}}\right) \Delta T,$$

where ΔT is the error of the ideal total power system. It is very large when T_r/T_{cal} is 10 or more, as it usually will be in order to avoid non-linearities when calibrating. See Fig. 3.3.

An improvement in this situation can be obtained by comparing the source temperature with a reference of known spectrum (usually flat) which differs in temperature only slightly from it. This is done by switching the input to the receiver between the antenna, T_{s1}, and the reference, T_{s2}.

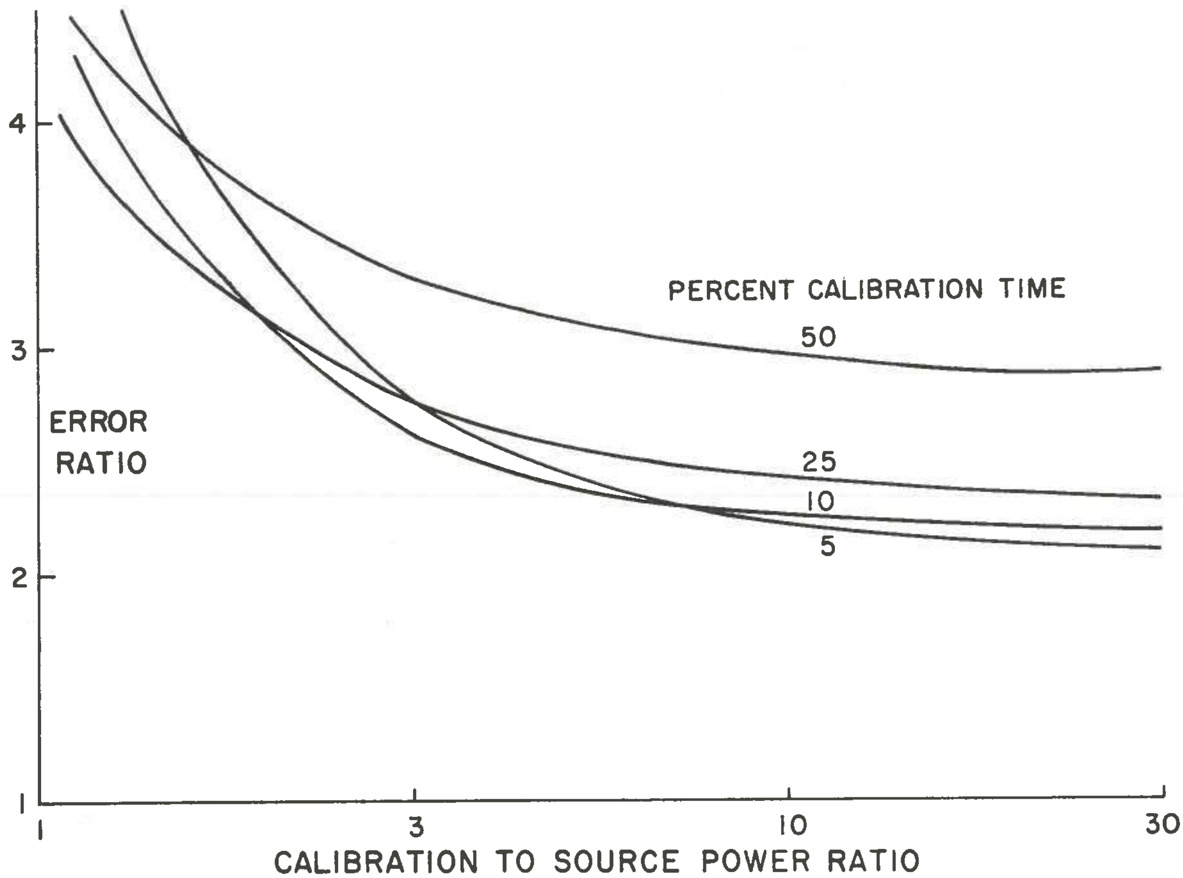


Fig. 3.3 Switched-to-unswitched receiver error ratio

Then

$$T_{s1} - T_{s2} = \frac{E_1 - E_2}{E_{cal} - E_1} T_{cal} .$$

We can see intuitively that the error of this expression will be at least double that of the ideal system because the result is a difference of two equally uncertain quantities and only half the time is available for each. Things will be a little worse than this because time is also needed for calibration. Figure 3.3 shows the variation of error with calibration to source temperature ratio for various % calibration times. We will further discuss the effect of unbalance in Part IV.

Of course, the introduction of a microwave switch in a low noise system is undesirable and can be avoided in a line receiver by switching frequency rather than switching inputs. The advantage in so doing is somewhat offset by the effect on the gain function of moving in frequency. If the modification in $G(f)$ is small, smooth over the band and stable, some allowance for it might be made. If on the other hand it must be calibrated out by going off source, observing time is again halved and errors are in turn doubled. We now need slightly more than *four times* as much observing time as an ideal total power receiver to obtain a given sensitivity.

3.2 THE 100-CHANNEL FILTER SYSTEM

Figure 3.4 illustrates the basic double conversion IF system. For a resolution of B there are 10 local oscillator lines spaced B and 10 spaced 10B all obtained either from an external synthesizer or from a self-contained set of crystal oscillators. To obtain a filter width of 10-kHz in the same matrix as is used for 100-kHz filters a design compromise is made in the filters. Instead of having identically tuned filters in all channels, each row of the matrix is filled with a set of filters tuned at 10-kHz steps across the band normally covered by one 100-kHz filter. Then all ten columns are fed from a common 1-MHz wide filter.

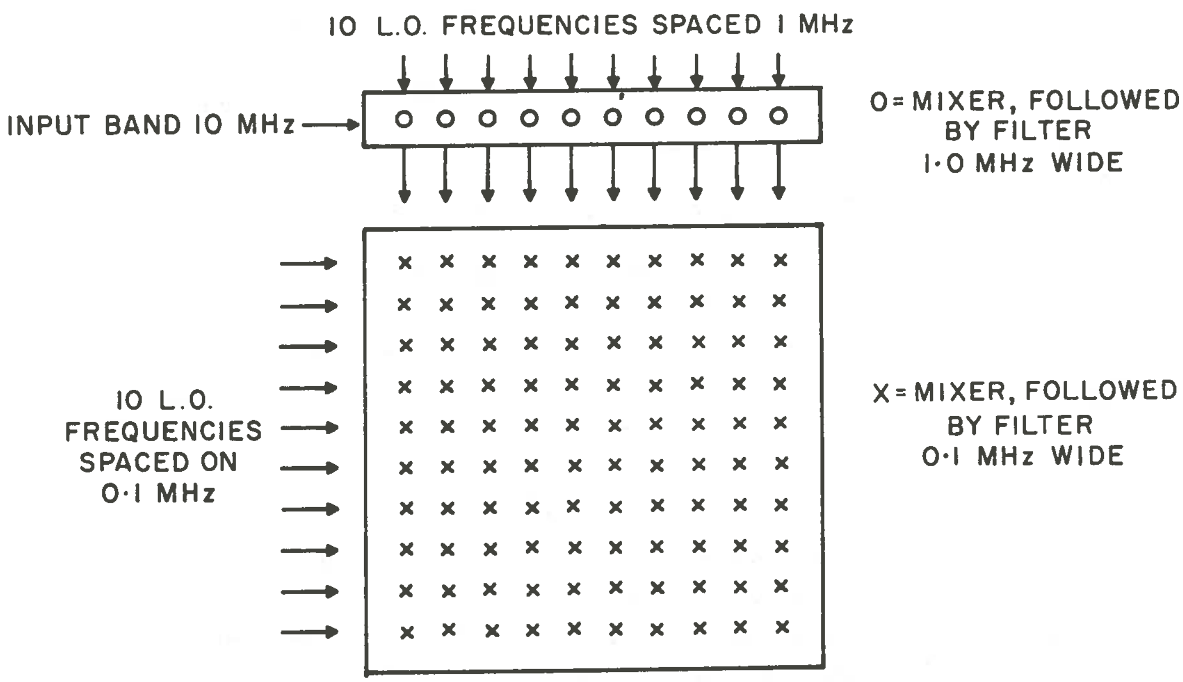


Figure 3.4 Intermediate frequency conversions for 100 channels

A switcher has been incorporated into the system between the first set of 10 1-MHz filters and the second set of 100 to accomplish the change required in the feed. The final filters themselves each contain a crystal which defines the 10-kHz bandwidth and center frequency. A switch across each crystal effectively removes it and the remaining selectivity due to tuned circuits gives 100-kHz bandwidth centered on a common frequency.

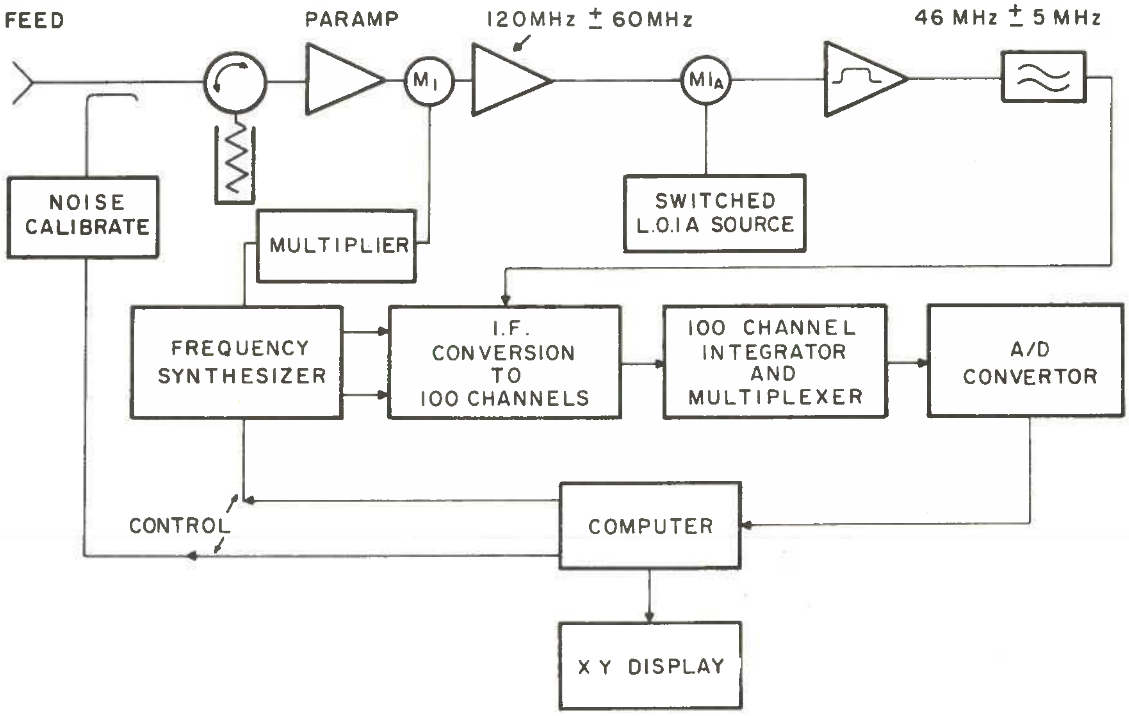


Figure 3.5 Filter receiver functions

Figure 3.5 is a function block diagram showing a microwave parametric amplifier coupled through a filter F_1 which defines the 10-MHz window of the spectrometer. Center frequency is controlled by the first oscillator frequency which can be chosen by computer or manually through the synthesizer. The output of each of the 100 channels is detected and passed through a short term (RC) integrator. A multiplexer samples the outputs at the end of each half switching cycle of the receiver input, whether it is being frequency or load switched. The samples are digitized and stored in computer memory in three sets, representing E_1, E_2 and E_{cal}. After about one minute the stored values are used to compute the 100 results, $T_{s1} - T_{s2}$, from an assigned T_{cal}. This set of temperatures is added to a store of previously acquired sets so that the spectrum may be integrated over a period as long as several hours if desired. A display allows the observer to watch the development of the spectrum. He can then make a record of it when he wishes. The details on observing are given in the Operating Procedure Section of this report.

3.3 DESIGN PROBLEMS

Spurious responses are plentiful in wide band receivers, especially when there are many local oscillator frequencies present. Their harmonics and the low order beats must be avoided in the IF.filters. Figure 3.6 illustrates the narrow range available to the final filter which has a 0.2 MHz bandwidth. Line A shows the final LO set (3.0, 3.1, . . . 3.9 MHz) and its harmonics together with some beats. Line B shows beats between frequencies of the first local oscillator set (30, 31, . . . 39 MHz). Of the slots clear in line A, the lower frequency one is eliminated by interference by the beats in line B when it is shifted up by the 3.0 MHz conversion. Line C is line B compressed in frequency

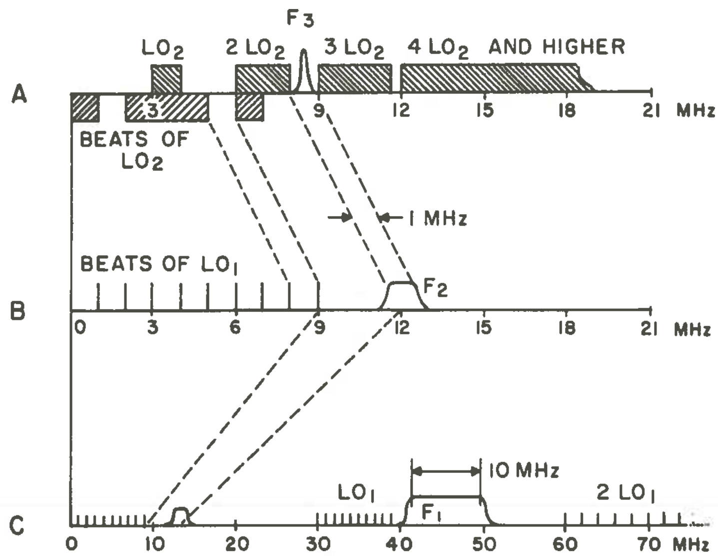


Figure 3.6 Interference from LO frequencies

to show the first local oscillator and its second harmonics. The first filter 10 MHz wide is set between these bands. The point is that once F_3 the final filter is chosen, the others F_2 and F_1 are set by the local oscillator frequencies. There is not much choice except perhaps in the use of the image band for F_1.

Less serious perhaps are mixer products of signal and local oscillator. If the mixers operate as nearly as possible to true multipliers these can be substantially reduced. For instance a dual gate FET mixer had most of these responses 8- to 20-db below a diode ring bridge. The price paid was in uniformity and stability of gain.

Resolution

The set of points, T_{out}, calculated by the computer from sums ΣE_1, ΣE_2, ΣE_{cal} and a known T_{cal}, lies on a curve which is the convolution of the input spectrum with the final filter response (Fig. 3.7). The smoothing effect of various filter shapes is illustrated in Fig. 3.8, expressed as the demodulation of a cyclic ripple on the input spectrum. Note that a rectangular filter is not especially desirable because of its response beyond $B/p = 1.0$. Also note that the curves (c) and (d) for a 3-pole filter and for a correlation receiver do not differ markedly. The 100-kHz filter is approximately equivalent to a 3-pole filter. On the other hand curve (e) for a single-tuned circuit illustrates the loss of resolution suffered by the 10-kHz filter which has single crystal selectivity. There is considerable correlation between outputs of adjacent filters in this case so that the ΔT estimate using the 3-db bandwidth is pessimistic by a factor of $\sqrt{\pi}$ (the factor is 1.33 for the 100-kHz filters). This is concomitant with the need for about three times as many single-tuned filters as rectangular ones to achieve equivalent resolution. Here we arbitrarily set the resolution limit or cut-off at the half-power point in the Fourier spectrum of the spectrogram.

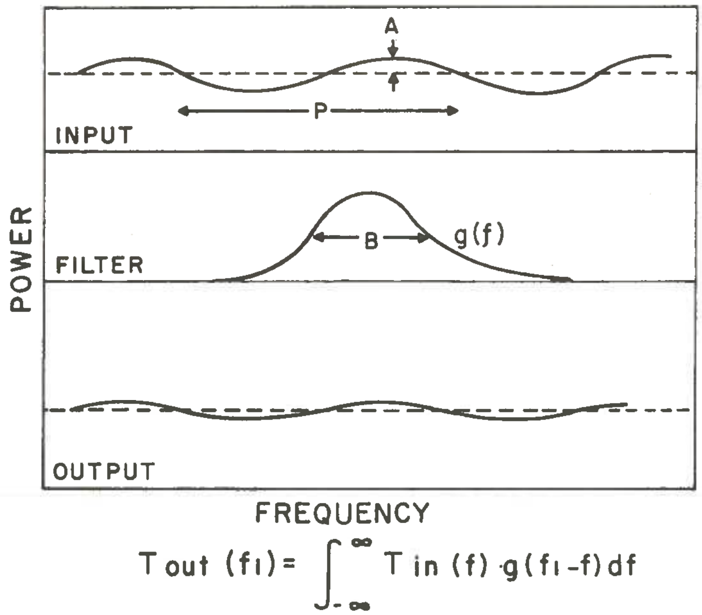


Figure 3.7 Convolution

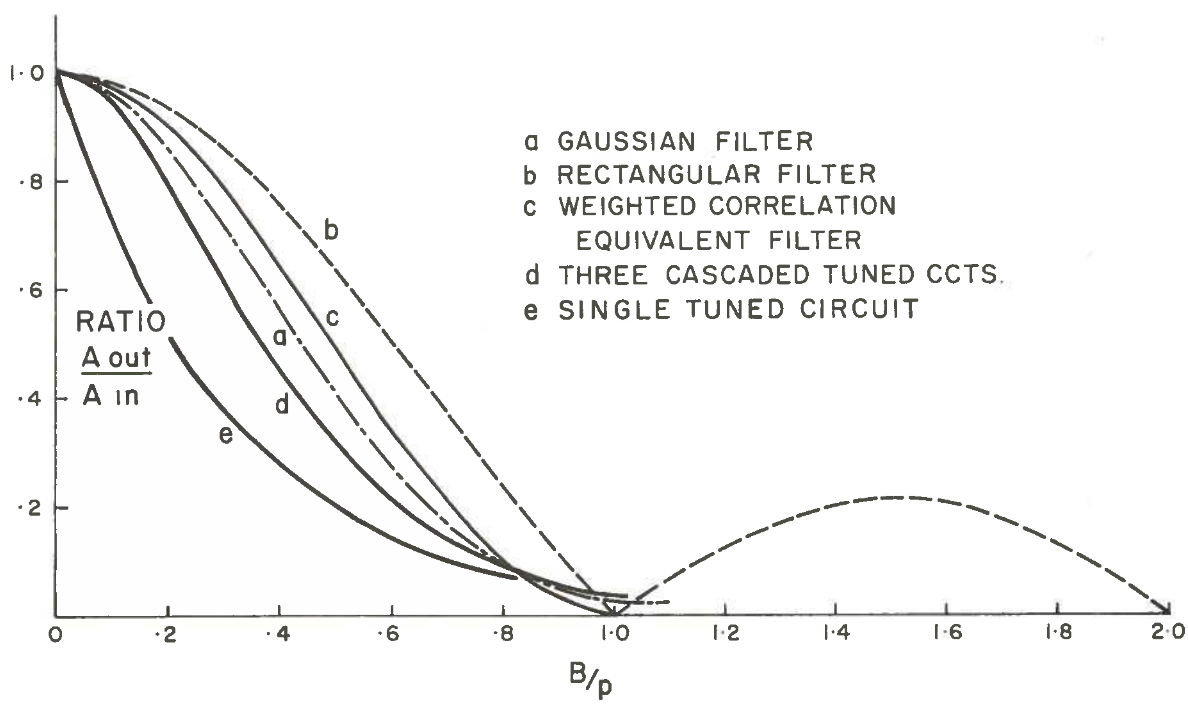


Figure 3.8 Suppression of cyclic ripple in output spectrum

Non-linearity

It is evident that the computation of output temperature

$$T_1 - T_2 = T_{cal} \frac{E_1 - E_2}{E_{cal} - E_1}$$

depends on the assumption of linearity in the system. Because we have measurable non-linearities in both the amplifiers and the detectors, it is possible to make an estimate of the errors involved. There will be two components in each case, a systematic error common to all channels and a random one due to channel differences. The latter part is most important since it adds to the uncertainty of detection of spectral features.

i) Amplifier saturation

Assume the straight line through AB in Fig. 3.9*a* defines the assumed gain, whereas the curve represents the real characteristic. The largest error between A and B lies at about the half-way point. If we assume a simple curve $y = a + bx + cx^2$, the error

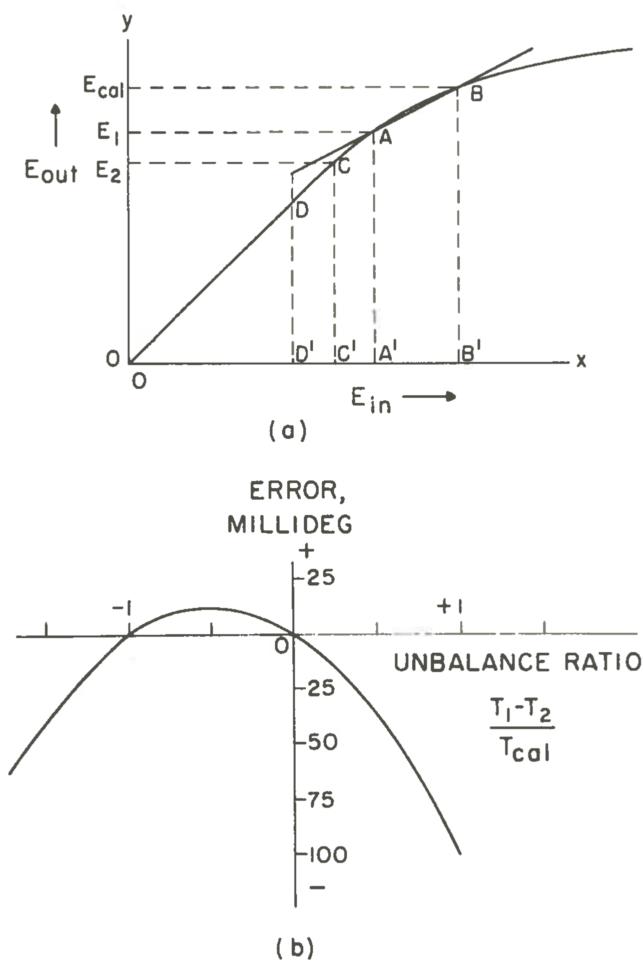


Figure 3.9 Temperature error due to amplifier non-linearity

at a point equidistant below A at C is three times as large. At D it is eight times as large as at the mid-point between A and B. If we assume a linear detector the abscissae are proportional to $\sqrt{T}$ and $OA' \propto \sqrt{T_1}$, $A'B' \propto \sqrt{T_{cal}}$, $OC \propto \sqrt{T_2}$. For small shifts along the curve we have plotted the error with respect to the ratio $\frac{T_1 - T_2}{T_{cal}}$ in Fig. 9*b*, which represents the actual effect of systematic curvature when $T_{cal}/T_{sys} = 0.1$ in the existing receiver. The random component, due to differences in curvature between channels will be somewhat smaller.

ii) Detector Curvature

The situation is similar to that for the amplifiers, except that the curvature of the characteristic is of opposite sign. Measurements on 100 detectors working in the output range of 1.3 to 1.8 V dc resulted in the error curve of Fig. 3.10. The systematic and random error was measured at point P, then assuming constant curvature around the operating point, the rest of the curve was deduced.

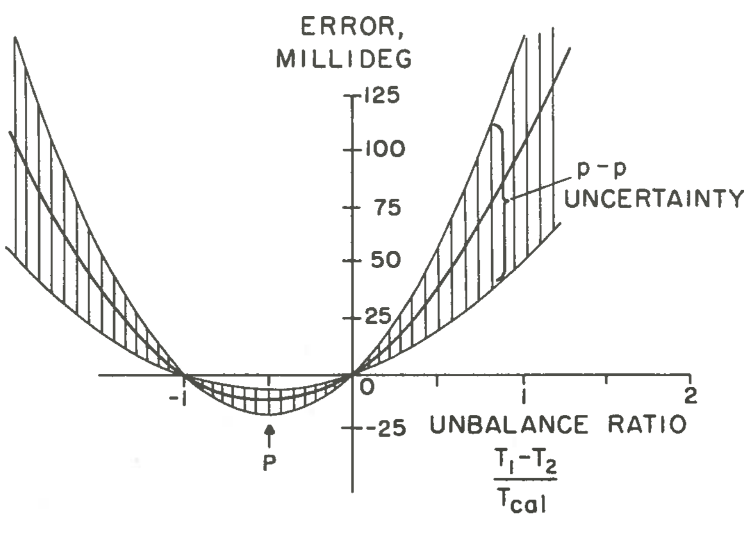


Figure 3.10 Temperature error due to detector non-linearity for $T_{cal} = 10°K$ and $T_{sys} = 100°K$

Finally in Fig. 3.11 the thermal and total non-linear uncertainties are plotted against unbalance ratio. In this case we have used the unfavourable, positive, unbalance ratio. There should really be no significant contribution from non-linearities until unbalance is at most equal to calibration temperature. At this point the thermal contribution alone is more than doubled.

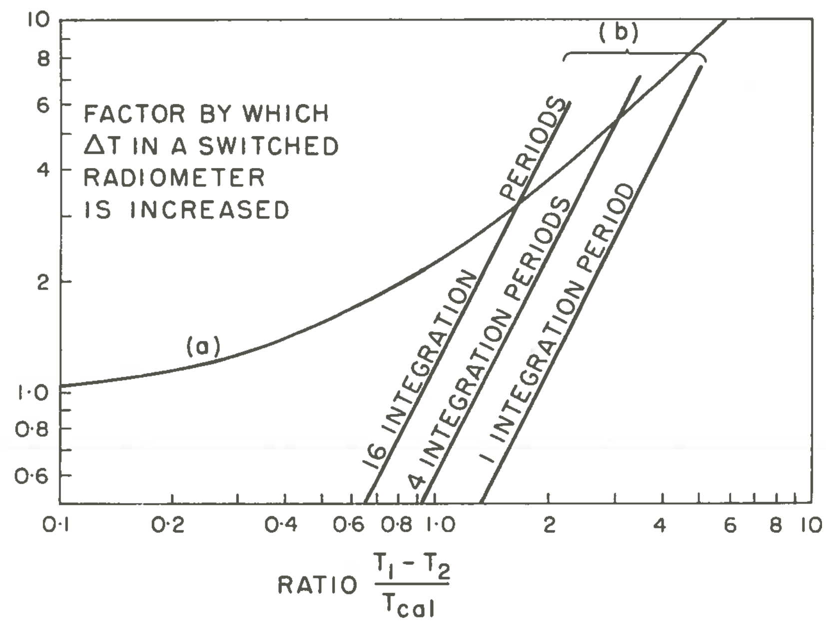


Figure 3.11 Temperature uncertainty in terms of unbalance
(a) Thermal noise contribution
(b) Non-linear contribution $T_{cal}/T_{sys} = 0.1$

Integration and Sampling

The desired output from the system is the best estimate in a given time of the noise power from each of the channels. The spectrum of the detected output of a filter contains a dc term plus an ac term extending from zero to B Hz where B is the final filter bandwidth. An ideal way to estimate the dc level would be to digitize the detector output and integrate in the computer. However, this would require 100 channels of sampling at at least 200 kHz rate – too fast for a single A/D converter. A method which results in some loss if it is to be simple is to use an analog RC integrator over the half switching cycle of the receiver front end. This is sampled across the 100 channels in about 7 msec with a multiplexer followed by a 12-bit A/D converter. The reason for loss of S/N ratio is quantizing and other added noise, coupled with a limited dynamic range at the input to the RC integrator. A detailed analysis follows resulting in the curves of Fig. 3.12 which illustrates two cases somewhere near the actual situation. It can be seen that when the optimum value of RC is used, the loss will be about 1.5 db when added noise (post-detection) is between 50 and 60 db below the dc level of the detector output.

Analysis

Refer to Fig. 3.12*a*, where the uncertainty in V_{out}, τ seconds after opening the switch, is of interest. The correlated power in this time delay is given by $R(\tau)$ and since the total power is $R(0)$, the uncertainty is given as a difference variance, $R(0) - R(\tau)$.

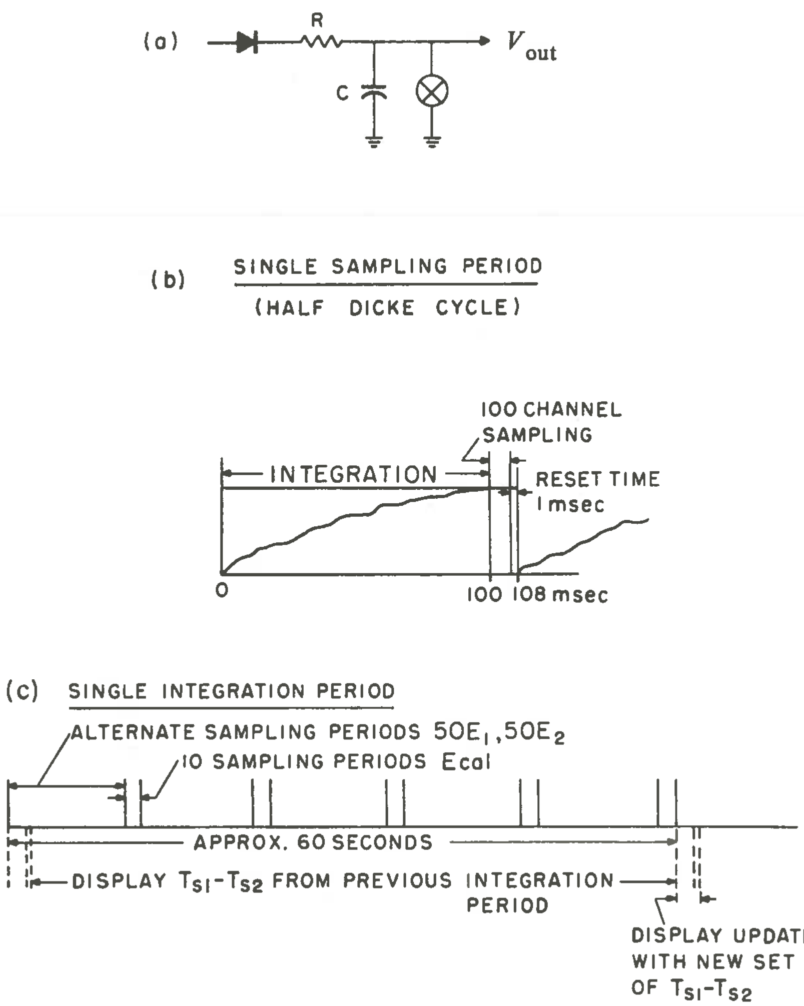


Figure 3.12 Time division of data acquisition and display

If we know the spectral power output of the detector and the frequency transfer function of the RC filter we can arrive at the transform of $R(\tau) \Leftrightarrow S_y(\omega)$. Assuming square law detection and a rectangular predetection noise band, B Hz, detector output

$$S_x(\omega) = 4a^2 A^2 B \quad ,$$

where a is the detector parameter and A is in the input spectral power density.

Then RC filter output

$$S_y(\omega) = \frac{4a^2 A^2 B}{1 + R^2 C^2 \omega^2}$$

The transform is

$$R_y(\tau) = \frac{2a^2 A^2 B}{RC} \cdot e^{-\tau/RC} .$$

Therefore the variance in estimate is

$$R(0) - R(\tau) = \frac{2a^2 A^2 B}{RC} \left(1 - e^{-\tau/RC} \right) .$$

At the same time the dc power out of the detector is $4a^2 A^2 B^2$ and out of the filter after τ seconds it will be

$$P_{dc} = 4a^2 A^2 B^2 \left(1 - e^{-\tau/RC}\right)^2$$

Radio of dc to ac power is therefore 2BRC $(1 - e^{-\tau/RC})$. This is curve (a) in Fig. 3.13, where it is obvious that the ratio is maximized as RC $\rightarrow \infty$. As this condition is approached the actual dc output power falls toward zero so that very little added noise after the filter corrupts the system. If we add noise due to 2 mv quanta in the A/D conversion when the

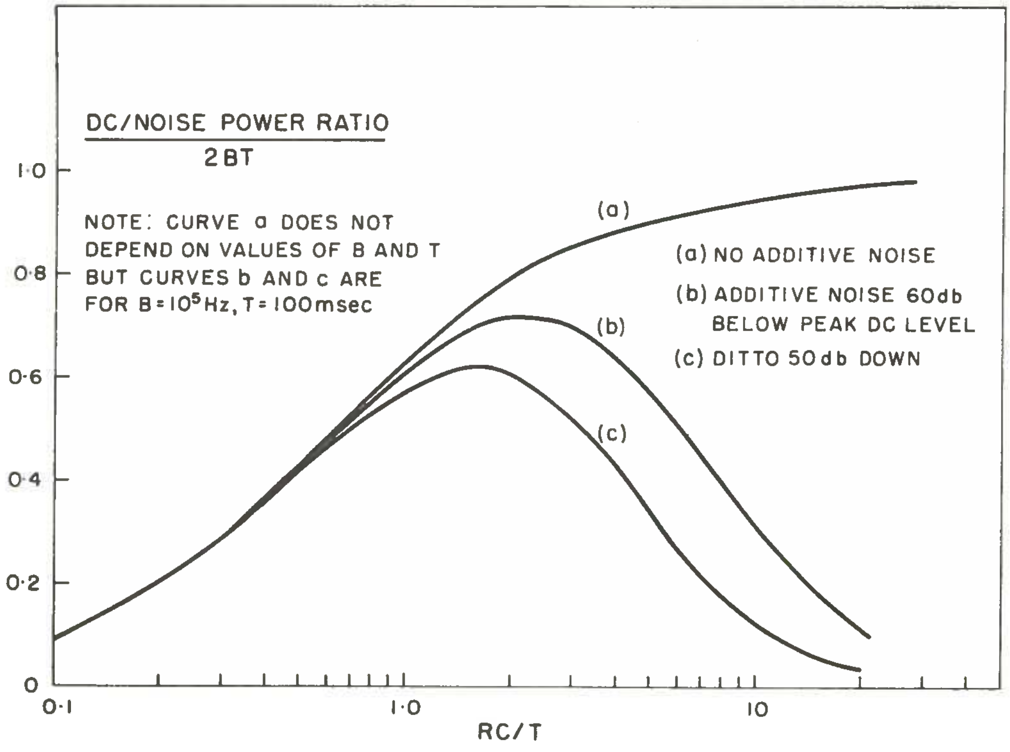


Figure 3.13 dc to noise power ratio for RC integrator

detector dc output is about 1.0 volt, this will amount to about 10^{-6} of the dc power, and curve (b) will result. A further degradation of 10 db, caused possibly by a noisy line to the computer, will give curve (c).

Finally, referring to Fig. 3.12*b*, the time budget shows what loss there is due to sampling and resetting at the end of each half Dicke cycle.

Figure 3.12*c* shows the make-up of one complete integration period which provides a new set of temperatures to update the display. Each set is derived from 25 seconds of actual data on E_1, also on E_2, and 5 seconds of data on E_{cal}. The actual elapsed time is about 59.5 seconds.

Commutation

Channels which behave differently can generate systematic errors which appear as uncertainties in a display of relative temperature. If it were feasible to cummutate all the filters through the frequency band so that each one contributed equally to every channel, the differences would disappear. This would require a 100 X 100 switch matrix in our case, a rather formidable instrument. Something similar though not quite so effective can be done by switching local oscillator feeds and the operation is much simplified when there are only two sets of ten oscillators. Fig. 3.14 shows how it is done with two 10 X 10 matrices.

Because we have incorporated a new set of filters (10 kHz) within the system designed originally for 100-kHz filters we have been forced, in an effort to simplify the hardware, to stagger the frequencies of the new set. Therefore it is not possible to commutate successfully when using 10-kHz bandwidth.

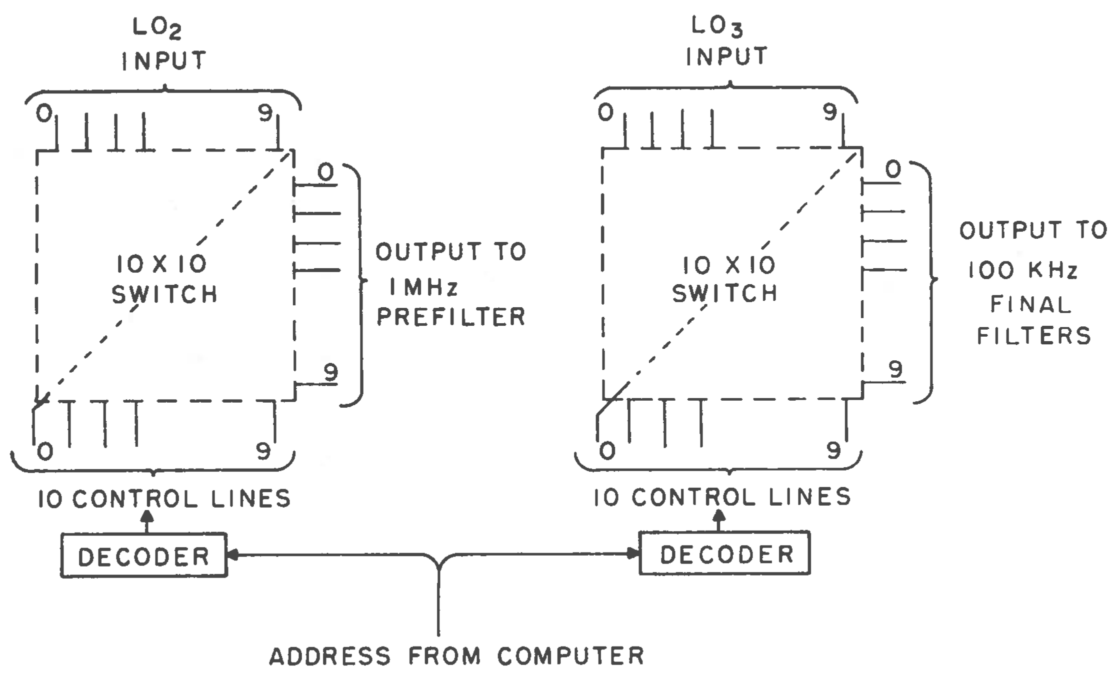


Figure 3.14 Commutation of local oscillators

IV. OPERATING CHARACTERISTICS

4.1 MODE SELECTION

The normal spectrometer operating modes are *load switching* and *frequency switching*, both at about 5 Hz determined by the sampling sequence (see Fig. 3.12). In fact the spectrometer does not distinguish between them and data are collected in exactly the same manner in the two cases. Frequency switching of the second local oscillator (LO_{1A}) is controlled by a switch on the spectrometer rack. In the OFF position LO_{1A} is 68 MHz, the 'signal' frame, and in the ON position LO_{1A} is switched from 68 MHz to 78 MHz, the reference frame, at 5 Hz. Load switching is controlled from the ferrite switch driver on the radiometer rack. A selector allows for Dicke switching or for holding on either antenna or cold load. The rate may also be switched from 5 Hz to 103 Hz, the standard rate for *continuum* observations with the radiometer.

Whatever switching mode is employed at the receiver input, there remains with the observer the option of whether or not to commutate the 100-channel outputs in order to reduce errors due to hardware differences. At present the technique of switching the local oscillator frequencies in lieu of actual commutation of the filters, which we have used in this receiver, can *not be used* for observations on the 10 kHz bandwidth because those filters are not tuned identically. The commutator is described briefly in Part III.

4.2 FREQUENCY SETTING

Frequency is set by the first local oscillator which is controlled through a multiplier by the synthesizer. The synthesizer may be set manually on fixed frequencies or it may be computer programmed to handle Doppler corrections. In the case of the 2.8-cm receiver the program computes the synthesizer frequency required given the desired center band (channel 50) frequency of the spectrometer window:

$$f_s = \frac{\text{frequency of channel '50'} - 114.5 + \delta(t)}{288} \quad \text{MHz}$$

where $\delta(t)$ is the Doppler correction. The magic number, 114.5 is the sum of the center frequency of the IF, 46.5, and LO_{1A}, 68 MHz. When the 10-kHz filters are used the magic number is 113.955 MHz in the same formula. Note that in both cases the channel labeled '50' is the 51st starting from channel '00', and the frequency used for it refers to the center of the channel.

The reference frequency band when in the frequency switching mode is 10-MHz above the signal band. Signal may be put into the reference band by typing in a frequency 10 MHz lower than actually desired. The record will be negative-going on display and plotter.

When we change filter bandwidth from 100 kHz to 10 kHz the computer automatically shifts the receiver local oscillator frequency in order to keep channel '50' on the frequency originally requested. The shift is needed to accommodate new IF intermediate frequencies within the spectrometer. If the computer is not controlling the first LO then the new window will move downwards by 545 kHz, almost covering the band previously displayed between channels 40 to 49.

4.3 LEVEL

The receiver output noise level can be set for working in that portion of the characteristic well below saturation but high enough to make post detector noise negligible. The nominal output of the system is 2.0 V dc but levels within 3 db of this are acceptable. The display produces a numerical output which is a 5 second summation of the signal voltage samples averaged over all 100 channels. The bit size of the A/D converter is 2 mV so the expected display for 2 V dc input to the computer is

$$\frac{5 \times 5 \times 2000 \times 100}{2 \times 100} = 25000,$$

when the rate is 5 Hz.

Therefore the nominal level setting is '25000' display units and this can be approximated, within 1 db, with the LEVEL SET attenuator on the console.

The display will also show the channel-to-channel fluctuations of output around the average. These could be within ±2 db or ±5000 display units at the nominal average level.

4.4 BALANCING

In a radiometer the balance between signal and reference portions of the switching cycle is made good in order to minimize the effect of gain changes between calibrations. For the spectrometer a more serious result of poor balance is the increase in output uncertainty caused both by thermal noise and differences in channel non-linearity. This was discussed in Part III and illustrated in Fig. 3.11. The unbalance should be less than 1% of the level. Nominally the level is 25000 units so a balance less than 250 is accepted.

When frequency switching, balance may be obtained by adjusting a gain modulator in the main IF path at 46.5 MHz (Fig. 4.1). An indication appears on the display in terms of 2 mV units accumulated from E_1 and E_2 over 5 second intervals. Thus we are reading a numerical difference $\Sigma E_1 - \Sigma E_2$ averaged over 100 channels. Each sum contains 25 samples as in the level setting operation.

Balance for the load switching mode may be obtained either with the gain modulator or with the addition of noise power to the antenna feed. The 'Noise Power Equalization' controls enable one to add up to 50°K.

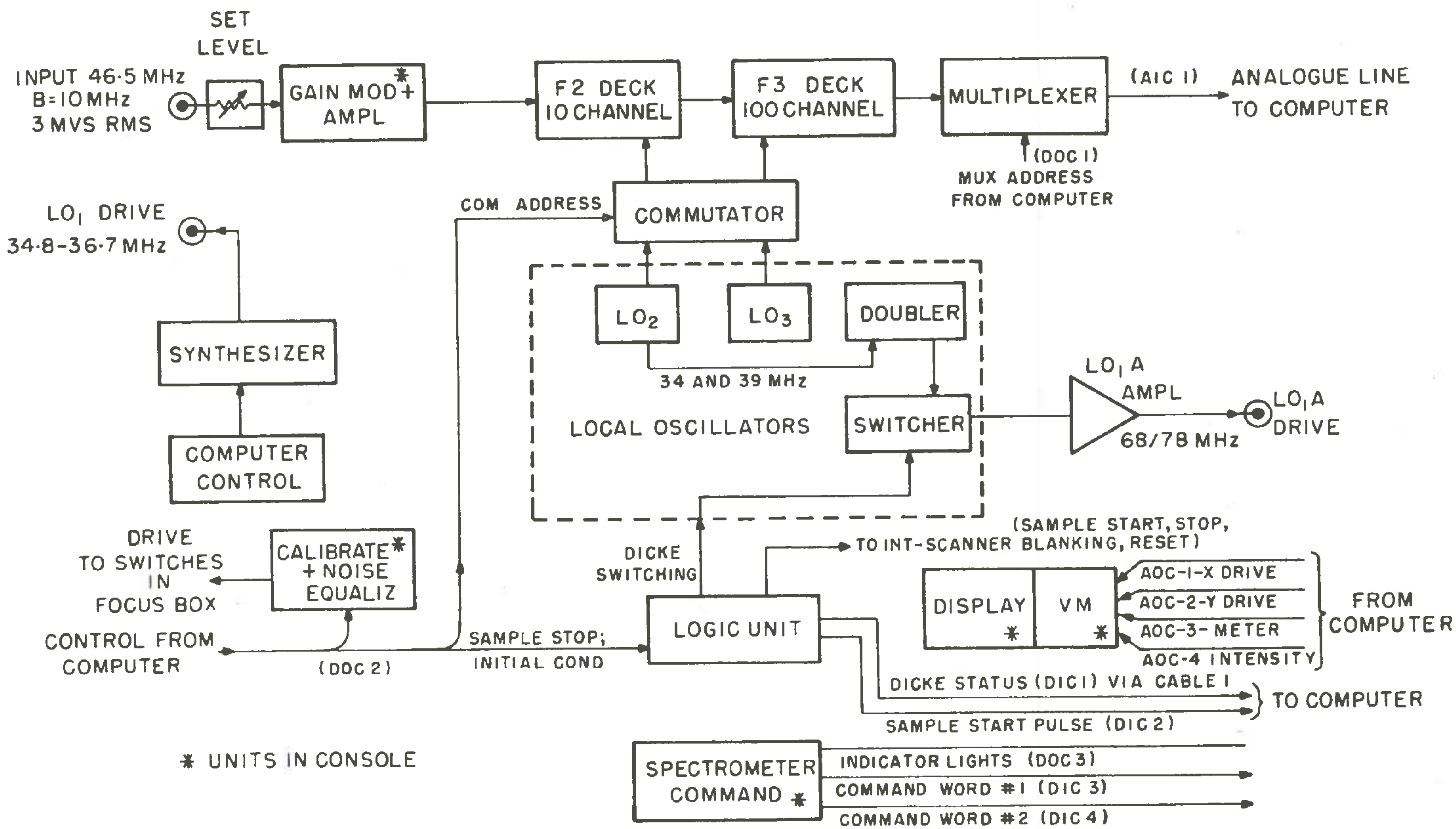


Figure 4.1 Spectrometer functional diagram

4.5 ON SOURCE OBSERVATION

Three states are measured; signal E_1, reference E_2 and calibration E_{cal}. The computation of output temperature is made after 250 100-msec samples each of E_1 and E_2 and 50 samples of E_{cal} have been accumulated according to the sequence in Fig. 3.12. The result, where $T_{out} = T_1 - T_2$ is

$$T_{out} = T_{cal} \frac{\sum_1^{250} E_1 - \sum_1^{250} E_2}{5 \sum_1^{50} E_{cal} - \sum_1^{250} E_1} .$$

The display will be the series of 100 values of T_{out} after one integration period (about 1 minute). To allow for the detector *voltage* linearity, the above expression is modified. The correction factor is an approximation in that it should be applied to each sample rather than to the sums. The second order error is neglected.

$$T_{out} = T_{cal} \frac{(\Sigma E_1)^2 - (\Sigma E_2)^2}{(5\Sigma E_{cal})^2 - (\Sigma E_1)^2} = T_{cal} \cdot \frac{\Sigma E_1 - \Sigma E_2}{5\Sigma E_{cal} - \Sigma E_1} \cdot \frac{\Sigma E_1 + \Sigma E_2}{5\Sigma E_{cal} + \Sigma E_1} .$$

As each set of T_{out} is produced it is added to a store to provide an integrated set for display. The values displayed are the differences, $T_{out} - (T_{out})_{AV}$ and $(T_{out})_{AV}$ is displayed numerically. ΣT_{out} may eventually deflect the trace off the display in the Y direction, at which point the operator changes scale factor.

The summation of P outputs of systematic spectral feature T_s will be $P \times T_s$. The noise outputs due to thermal and other random noise will add to $\sqrt{P}\, T_s$. Hence the signal to noise ratio will gradually improve by $\sqrt{P}$. Since the signal may be kept relatively constant by changes in the scale factor, the display noise will gradually diminish.

The program arbitrarily assigns a basic scale of 1 millidegree for each unit (2 mV) step in the D/A conversion. Therefore when the display sensitivity is adjusted for a 4-cm deflection with full 4.0 volts input, the basic scale factor is 500 millidegrees per cm (3 on selector). Because in successive integrating periods the data (T_{out}) are summed, the scale will be divided by P at the time the Pth period is being displayed. The initial scale factors, set by the thumbwheel on the control panel are

Dial	Scale factor millidegrees per cm
0	50
1	100
2	250
3	500
4	1000
5	2500
6	5000
7	25000
8	50000
9	variable

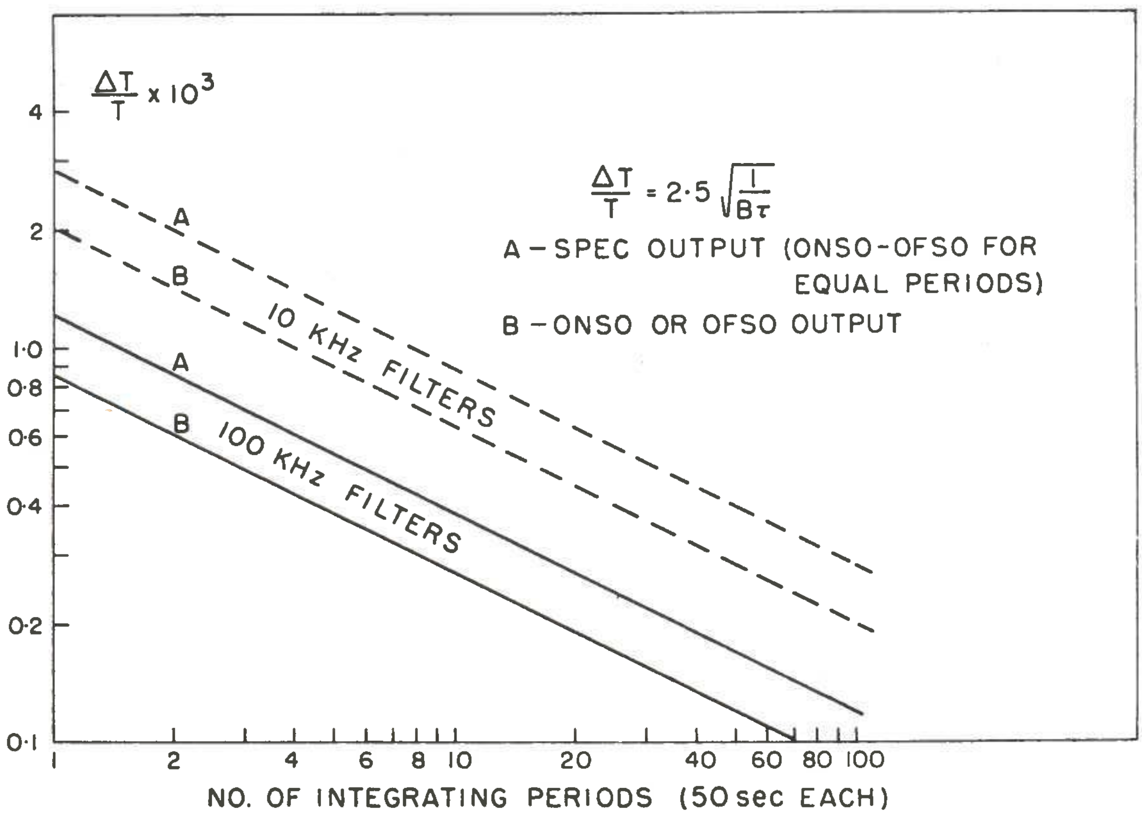


Figure 4.2 Thermal noise uncertainty of spectrometer output

The noise level on the display due to thermal noise at the receiver input should approach that given by Fig. 4.2. Here we have allowed for a sampling loss at 1 db and for the effect of filter shape on reception bandwidth. It is because of this latter consideration that the noise level of the 10 kHz filters is less than $\sqrt{10}$ times that of the 100 kHz filters, as explained in Part III. Records of the display may be stored on punched paper tape and on an X-Y plot.

4.6 NOISE POWER EQUALIZATION FOR FREQUENCY-SWITCHED RADIOMETER

The result T_{out} contains a number of contributions from various sources.

$$T_{out} = T_{S1} - gT_{S2} + T_{A1} - gT_{A2} + T_{R1} - gT_{R2} \quad (1)$$

where subscript s refers to source, A to antenna plus background (spillover), R to receiver, 1 to signal frequency and 2 to reference frequency. The factor g is the gain ratio between the signal and reference conditions. It is, of course, a function of frequency.

(If we are not frequency switching but load switching

$$T_{A2} = 0 \text{ and } T_{R1} = T_{R2} \text{ so } T_{out} \doteq T_{S1} + T_{A1} - gT_{S2} + T_{R1}^{(1-g)}$$

where s2 refers now to the cold load. The term g now contains no function of frequency and large terms may be reduced by adjusting the gain modulator.)

The terms in (1) containing g may introduce a fairly large uncertainty in the result, expecially those as large as T_R. These can be almost eliminated if OFF SOURCE observations are made under the same conditions so that

$$T_{out} = T_{O1} = gT_{O2} + T_{AO1} - gT_{AO2} + T_{R1} - gT_{R2} \quad (2)$$

Subtracting (2) from (1) gives

$$(T_{out})\,A - (T_{out})\,B = T_{S1} - T_{O1} - g(T_{S2} - T_{O2}) + T_{A1} - T_{AO1} - g(T_{A2} - T_{AO2})$$

The only large term containing g which is possibly left is $T_{S2} - T_{O2}$. The purpose of noise power equalization is to add noise power to T_{O2} until it nearly equals T_{S2}. Therefore, this part of the program stores the last integration period set of ΣE_{S2} values and presents the difference $\Sigma E_{O2} - \Sigma E_{S2}$, allowing for the difference of 10:1 in integrating time. The display is actually

$$\frac{10\Sigma E_{O2} - \Sigma E_{S2}}{5\Sigma E_{cal} - \Sigma E_{S1}} \cdot T_{cal}$$

and can be used as an estimate of the temperature difference between ON and OFF source. With the dish off the source, the observer adjusts E_{O2} by adding noise power from a plasma noise tube at the receiver input, until the display averages zero. This is very similar to the Dicke Mode Balancing operation. It takes 5 seconds to renew the display with a fresh estimate of equalization. When it is completed, the average value of E_{02} will be nearly equal to the average of E_{S2} which will come reasonably close to the desired result $T_{02} - T_{S2} \rightarrow 0$.

4.7 OFF SOURCE OBSERVATION

At this stage of the game we are simply repeating the ON source observations with the dish pointed to a 'quiet' portion of the sky. We expect no spectral features in T_{01} so that when the final result (T_{out})B is subtracted from (T_{out})A stored from the ON source portion, the result will contain

$$T_{S1} - T_{01} \text{ plus some small residual terms.}$$

It should be borne in mind that to eliminate the undesirable terms in the ON source observation we had to *double* observing time plus run the risk of drifting paramp response shape in the receiver which could nullify the advantages. Therefore, it is probably wise to alternate between ON and OFF source frequently enough to avoid errors due to drifting paramp response shape.

Minimum error results from equal times on each position but in any case the program keeps track of the number of integrating periods and produces a final result:

$$\frac{(T_{out})A}{P} - \frac{(T_{out})B}{Q} .$$

4.8 CALIBRATION TEMPERATURES

The display temperature scale depends on the value of calibration temperature supplied to the computer (see 2.3). Two discrete values are indicated at the upper and lower limit of the calibration level attenuator by means of a code derived from the panel switch positions. A peculiarity of the scheme is that while intermediate levels of calibration can be obtained *between* the attenuator limits, the code is set by the direction the attenuator is driving. If it was last driven toward the upper limit, code 5 (for 10°) will prevail, otherwise code 2 (for 1°) will be the index.

Determination of T_{cal}

This may be done in the usual manner using either a standard source if the receiver is mounted on the telescope or otherwise the cold load-attenuator method. In both cases received noise power may be measured by the SET LEVEL mode of readout. In this mode, integrated values of total power when the Dicke switch is on the signal phase are presented on the display in terms of voltage output of a linear detector. Calibration noise power may be added manually from the 'Calibrate Panel' and the new level noted. An average value of several readouts is desirable in order to reduce random errors, although each one is the summation of 25 100-msec intervals averaged over 100 channels. For the 100-kHz resolution (B = 10 MHz)

$$\frac{\Delta T}{T} = \frac{1}{5000}$$

which is sufficiently accurate since gain drifting introduces a larger uncertainty.

Method

Reading the display on SET LEVEL when the level is at about 25000, record several successive values of total power in each of the following states:

ΣE_1 output with CAL OFF and OFF STD source

ΣE_{cal} output with CAL ON etc.

ΣE_s output with CAL OFF and ON STD source of known temperature T_s.

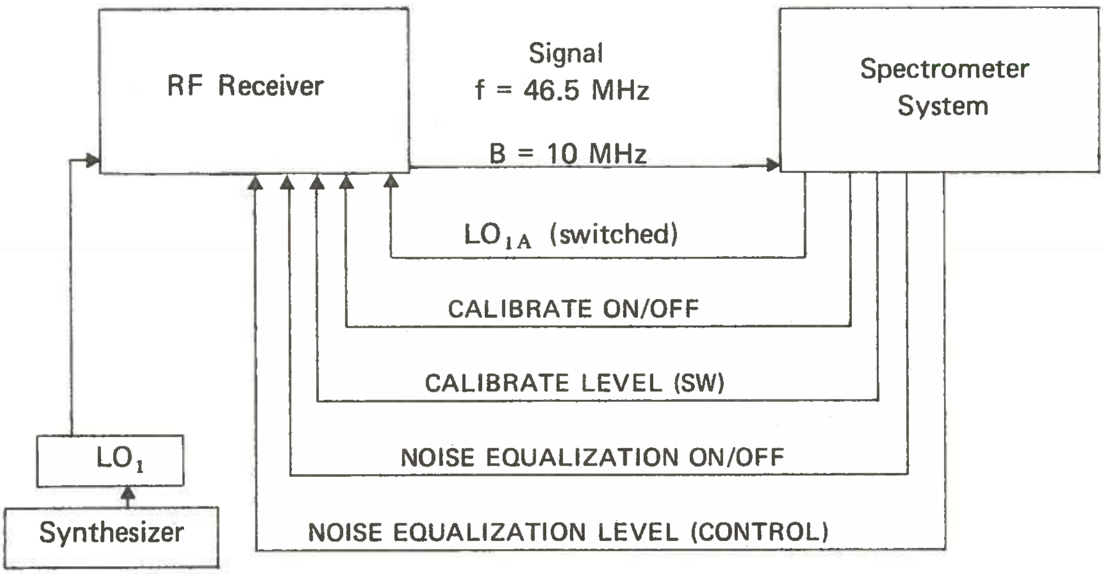
Calculate

$$T_{cal} = T_s \frac{\Sigma E_{cal} - \Sigma E_1}{\Sigma E_s - \Sigma E_1} \cdot \frac{\Sigma E_{cal} + \Sigma E_1}{\Sigma E_s + \Sigma E_1}$$

The final factor is a first order correction for the linear detector.

V. REQUIREMENTS FOR OPERATING THE SPECTROMETER WITH RF FRONT ENDS OTHER THAN THE NRC DESIGN

There are several functions tying the rf receiver to the spectrometer. Some are optional, the rest are required.



SIGNAL This uses a coaxial line (RG213) from telescope to spectrometer console. The noise level in a 10-MHz band should be about 10 mv rms at receiver output.

LO_{1A} This is the frequency switching local oscillator line, delivering 68/78 MHz at about 20 mv rms to the front end. Conversion in the mixer is from 120 MHz wide band IF to 46.5 MHz IF, so that any receiver using 120 MHz wide band IF is compatible with the system as it stands. Other frequency bands could be accommodated by further conversion or by changing frequency on the LO_{1A} line. The switcher is located in the spectrometer rack where some choice of the two frequencies is offered at taps on the LO_{1A} driver:

LO_{1A} Taps (MHz)	Frequency	Line Driver	Coax
30, 31, 32, ... 39	Mult X 2	(-1 db) 64–82 MHz	Line No. 35

Normally (to avoid spurious responses) we use any pair of taps between 34 and 39 MHz, so that frequency shifts of 2, 4, 6, 8, 10 are available.

CALIBRATION

Switching is carried on a 17-pin connector cable (No. 45) along with the other two following control functions. At present there is a positive pulse transmitted on separate wires for ON and OFF states. The computer program requires the changeover time to be less than about 5 msec.

An auxiliary BNC output at the rear of the panel provides logic level (+3.5 V) drive for control of other receivers. Calibration level may be set by a reversible 60 cycle motor controlled by the front panel lever switch. The supply is 12.6 V.

NOISE EQUALIZATION ON/OFF

A manually controlled switch on the console operates a 28-volt electro-mechanical switch to cut noise power to the balancing arm of the radiometer.

NOISE EQUALIZATION LEVEL

A manually controlled switch on the console increases or decreases noise power by reversible ac meter control on 3 wires (12 V, 60 Hz).

The last two functions are also optional. If other means of balancing are used they may be wired in using control cable No. 45 or other unused cables. Refer to the service manual for details on the pin connections and levels used for control functions.

LO_1 An alternative frequency switching scheme is to switch the *first* local oscillator, if it can be shifted as rapidly as 10 MHz in a few milliseconds. (The time is limited by the multiplexer scanning interval (6–8 msec)).

This may have the advantage of leaving a wider choice in front end design. The bandwidth following the first mixer should be flat over a maximum of 10 MHz.

The computer program is arranged to accept either a single frequency command for the synthesizer in the case of LO_{1A} switching, or a dual frequency command. In the latter case the synthesizer is automatically switched at Dicke rate and may be used for controlling the LO_1 frequency. A time variable to take care of earth rotation Doppler is also accounted for in either case.