UNCLASSIFIED

AD NUMBER
ADB004583
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; APR 1975. Other requests shall be referred to Rome Air Development Center, Griffiss AFB, NY 13441.**
AUTHORITY
RADC ltr 3 Dec 1979

THIS PAGE IS UNCLASSIFIED

RADC-TR-75-120
Final Technical Report
April 1975

ADAPTIVE BANDPASS TUNABLE FILTER (AS-11B-1)

Bendix Research Laboratories

Distribution limited to U. S. Gov't agencies only; test and evaluation; April 1975. Other requests for this document must be referred to RADC (IRRG), Griffiss AFB NY 13441

Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York 13441

PREFACE

This project is a continuation of various efforts to improve the performance of the AS-11B-1 automated analytical stereoplotter. The study and filter development work were performed at Bendix Research Laboratories (BRL), Project Number 4557, and experimental work was performed at Rome Air Development Center. The RADC program monitor was Mr. A. Fanelli (IRRG), whose assistance during the checkout and experimental evaluation phases of the project is gratefully acknowledged.

Section 3.2 and Appendix B of this report document computer programs developed on this project. These sections of the report constitute the program documentation required as line item A002 of the contract.

This report has been reviewed and approved for publication.

APPROVED: Anthony Fanelli

ANTHONY FANELLI
Project Engineer

APPROVED: Howard Davis

HOWARD DAVIS
Technical Director
Intel & Recon Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

Do not return this copy. Retain or destroy.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER
RADC-TR-75-120

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE *(and Subtitle)*
ADAPTIVE BANDPASS TUNABLE FILTER (AS-11B-1)

5. TYPE OF REPORT & PERIOD COVERED
Final Technical Report
Feb 74 - Jan 75

6. PERFORMING ORG. REPORT NUMBER
BRL Report No, 7505

7. AUTHOR*(s)*
James O. Abshier

8. CONTRACT OR GRANT NUMBER*(s)*
F30602-74-C-0134

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Bendix Research Laboratories
Bendix Center, 20800 Civic Center Drive
Southfield, MI 48076

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
62702F
55690141

11. CONTROLLING OFFICE NAME AND ADDRESS
Rome Air Development Center (IRRG)
Griffiss AFB NY 13441

12. REPORT DATE
April 1975

13. NUMBER OF PAGES
34

14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)*
Same

15. SECURITY CLASS. *(of this report)*
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
N/A

16. DISTRIBUTION STATEMENT *(of this Report)*
Distribution limited to U. S. Gov't agencies only; test and evaluation; April 1975. Other requests for this document must be referred to RADC (IRRG), Griffiss AFB NY 13441.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*
Same

18. SUPPLEMENTARY NOTES
RADC Project Engineer:
Anthony R. Fanelli (IRRG)
AC 315 330-7534

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*
Filtering, Electronics Tunable Filtering Scanning, Bandpass Filtering.

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*
A study was performed to determine the feasibility of providing adaptive tunable video bandpass filtering on an AS-11/B1 automated analytical stereoplotter. Various active filter forms were studied to determine their applicability to the AS-11/B1 tunable video filtering task. A digitally tuned analog filter type was selected, and experimental filter hardware was developed. Experimental software for controlling the filter was also developed. Experiments performed significantly reduced the number of searches and manual assists required under certain model conditions.

DD FORM 1 JAN 73 **1473** EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL EVALUATION

This effort involved a study and experimentation to determine the feasibility of providing adaptive tunable bandpass video filtering on an AS-11/B1 automated analytical stereoplotter.

To accomplish this, several alternative forms of tunable filters were studied. Several types of active analog filters and various tuning schemes were considered for the application but found unsuitable. A digitally tuned active analog filter was ultimately selected for the application.

With this filter installed, the AS-11/B1 system is able to more successfully cope with conditions of poor correlation. The number of searches and manual assists required were significantly reduced, and a slight improvement was obtained in plotting velocity and accuracy. Any decision to provide video filtering in Production AS-11/B1 systems should be held in obeyance until a more comprehensive test program can be conducted. This will involve testing with a larger number of models of various formats, focal lengths and resolution, and of varying terrain types. Such a program is planned to be undertaken and results will be available from RADC/IRRG by mid FY76.

Anthony Fanelli
ANTHONY FANELLI
Phys. Scientist

SECTION 1

INTRODUCTION AND SUMMARY

Previous studies of video filtering requirements for AS-11B-1 type systems indicated that the video bandwidth normally used in these systems was excessively large. During the Advanced Correlation Techniques II Study (Contract F30602-70-C-0037), frequency spectrum plots of video signals were made for a wide variety of photographic images. These spectrum plots indicated that there was usually little or no signal information in the upper part of the video passband, and that a video signal-to-noise ratio improvement could be obtained by reducing the upper cut-off frequency of the video filter. A subsequent memorandum documenting these advanced correlation techniques study results recommended changes to the normal AS-11B-1 video filters which resulted in improved system performance. These changes were eventually implemented in the AS-11B-1 systems. During the TA3/PA and AS-11B-1 Improvement Study (Contract F30602-71-C-0228), video spectrum plots were made using the higher resolution TA3/PA system. These plots also indicated little or no signal information in the upper part of the video passband. Both the AS-11B-1 and the TA3/PA video spectrum studies indicated that the video frequency content varied widely throughout typical photographs. It was therefore considered desirable to provide video filtering on the AS-11B-1 system which could be adaptively controlled to pass only useful signal information and reject noise. This would extend the system's ability to accommodate wide variations in photographic image content.

The objectives of the tunable video filter study were to implement experimental adaptive tunable video filters on the AS-11B-1 system and evaluate their effects on system performance. To accomplish this, several alternative forms of tunable filters were studied. Several types of active analog filters and various tuning schemes were considered. Digital filters were also considered for the application but found unsuitable. A digitally tuned active analog filter was ultimately selected for the application. Breadboard models implementing the selected filter scheme were designed and fabricated. Computer program modifications for adaptively controlling the filters were also developed. The tunable video filter experimental hardware and software were integrated with the AS-11B-1 system and checked out. Experimental evaluation was then performed to determine system performance improvements.

Experimental profiling tests with the adaptive tunable filters showed reduced searching and manual assistance for poor input photographic materials. For good models, improvements in speed and accuracy were slight. With adaptive video filtering, the system exhibited an increased tendency to plot when lost, indicating that correlation thresholds and plotting strategies needed to be reoptimized when using the filters. Another possible solution to this problem is to use different video filtering for measuring correlation than is used for measuring parallax. Correlator gains tests indicated that the scan size strategies should also be reoptimized when using adaptive filters on poor photographic models. It was determined that 4-pole filtering (as opposed to 2-pole) is neither necessary nor desirable for the AS-11B-1 adaptive tunable video filters. This is significant because 2-pole filters require less hardware to implement than 4-pole filters.

Section 2 of this report describes the tunable video filter study and experiments, including background, procedure, results, conclusions, and recommendations. Section 3 describes the experimental tunable video filter hardware and software developed for the experiments. Appendix A discusses the applicability of digital filters to the AS-11B-1 adaptive video filtering task. Appendix B documents some experimental filter frequency control strategy and modifications used during experimental evaluation of the filters.

SECTION 2

TUNABLE VIDEO FILTER STUDY AND EXPERIMENTS

This section describes the study and experiments to determine the feasibility of implementing adaptive tunable video filtering on the AS-11B-1 system. In Section 2.1, background on AS-11B-1 video filtering is presented. Section 2.2 describes the study and experimental work performed, including filter type selection, experimental hardware and software development, and experiments performed on the AS-11B-1 system. Section 2.3 presents experimental results and conclusions. Section 2.4 discusses recommendations based on results of the experimental program.

2.1 BACKGROUND

In the AS-11B-1 automated stereoplotter system, video filtering is employed to reduce unwanted noise on the image information signals and to attenuate image information which is of little value in determining image displacements (parallax). In the AS-11B-1, both highpass and lowpass filtering are employed. Highpass filtering is used to attenuate low frequency image signals and low frequency noise. Low frequency imagery is not very useful for measuring parallax, but is usually dominant in typical photographic images. If this low frequency information were not attenuated, it would tend to capture the limiters and suppress weaker but more useful high frequency image signals. Lowpass filtering is employed to reject noise above the upper cut-off frequency of the video passband. For good system performance, the upper cut-off frequency of the video filters should be matched in some sense to the upper limit of useful information in the signal spectrum. In the AS-11B-1 system, the upper cut-off frequency should be selected to provide good signal-to-noise ratio (SNR) consistent with good correlator parallax gains. The spectral content of photographic images generally varies rather widely throughout a typical aerial photograph. This necessitates the use of some form of adaptive control to insure that sufficient image information is obtained from the photographs for adequate parallax measurement. The normal AS-11B-1 system employs adaptive control of scan size to adjust the photographic area scanned. Varying the scan size also changes the scan velocity and thereby changes the relationship between spatial frequencies and video frequencies. Increasing the scan size causes lower spatial frequencies to generate higher video frequencies. The video filters, which in the normal system are fixed in frequency, then pass information from a lower segment of the image spectrum. Increased scan size also, of course, causes a larger area of the photograph to be scanned. Reducing the scan size causes the video filters to pass a higher segment of the image spectrum. Adaptive scan size control, therefore, is a form of system bandpass control since it determines what portion of the image spatial frequency spectrum is passed by the system.

Since the video passband of the normal AS-11B-1 system is fixed, it always passes a fixed amount of time-dependent PMT shot and CRT phosphor noise. By adaptively controlling video passband in addition to scan size control, time-varying noise can be reduced in situations where the spectrum of the image information does not completely fill the video passband. This usually occurs in low image detail areas of the photograph such as open field areas. These situations typically cause the system to perform poorly. The adaptive tunable video filter study and experiments of this project were undertaken primarily to determine the extent to which system performance can be improved in these situations by using tunable video filters.

2.2 STUDY AND EXPERIMENTS

The objectives of this project were to develop adaptive bandpass tunable video filters for the AS-11B-1 and conduct experiments to determine their effects on system performance. To develop the tunable filters, a study was made of various types of active filters. These filters generally consist of resistor-capacitor networks in conjunction with one or more operational amplifiers to form a second-order filter section. Combinations of these simple sections can be cascaded to form more complex filters.

Several of the various filter forms considered are shown in Figure 2-1. The first circuit (a) is a single amplifier form which uses an infinite-gain operational amplifier. The second circuit (b) uses a single fixed-gain amplifier with a gain of K. The third form (c) uses three infinite-gain amplifiers. In each of these circuits, the frequency of the filter section can be varied by varying either resistors or capacitors in the circuit. For computer control of frequency, binary weighted combinations of resistors or capacitors can be switched in and out of the circuits to achieve tuning. Resistor tuning was adopted for the tunable video filter since resistors are readily available in a wider range of values than are capacitors.

Several methods for switching the resistor networks were considered. They included reed relays, junction field effect transistors (JFET), and metal oxide semiconductor field effect transistors (MOSFET). Reed relays would work with all three circuits of Figure 2-1, but they have a slower switching time than the transistors. Moreover, they have a limited lifetime, which would increase maintenance cost if a production version of the filter was eventually developed. (This would not be a significant problem for the experimental units.) Because of the need to refer the gate drive of a JFET to a low impedance source, JFETs can only be used in circuit (c) of Figure 2-1. This circuit is tuned by varying R_1 and R_2 in unison. Both of these resistors have one end connected to a low impedance operational amplifier output. The MOSFET switches considered for this application would work in all three circuits to some extent, but would be most suitable in circuit (c). In circuits (a) and (b), stray capacitances of the switches could affect circuit operation adversely. The MOSFET switches exhibit a nonlinear dynamic resistance characteristic which, for this application, limits the resistance values which can be used in the circuit to rather high values. It was therefore decided to use circuit (c) and use JFET switches to control tuning resistances.

Although the circuit of Figure 2-1(c) uses two more amplifiers than circuits (a) and (b), it has some rather attractive features. In this circuit, highpass, lowpass, and bandpass outputs are available simultaneously. The frequency and damping characteristics can be tuned independently, making the circuit easy to use. Frequency tuning is accomplished by varying R_1 and R_2 or C_1 and C_2. Damping is changed by varying R_3. In the filter imple-

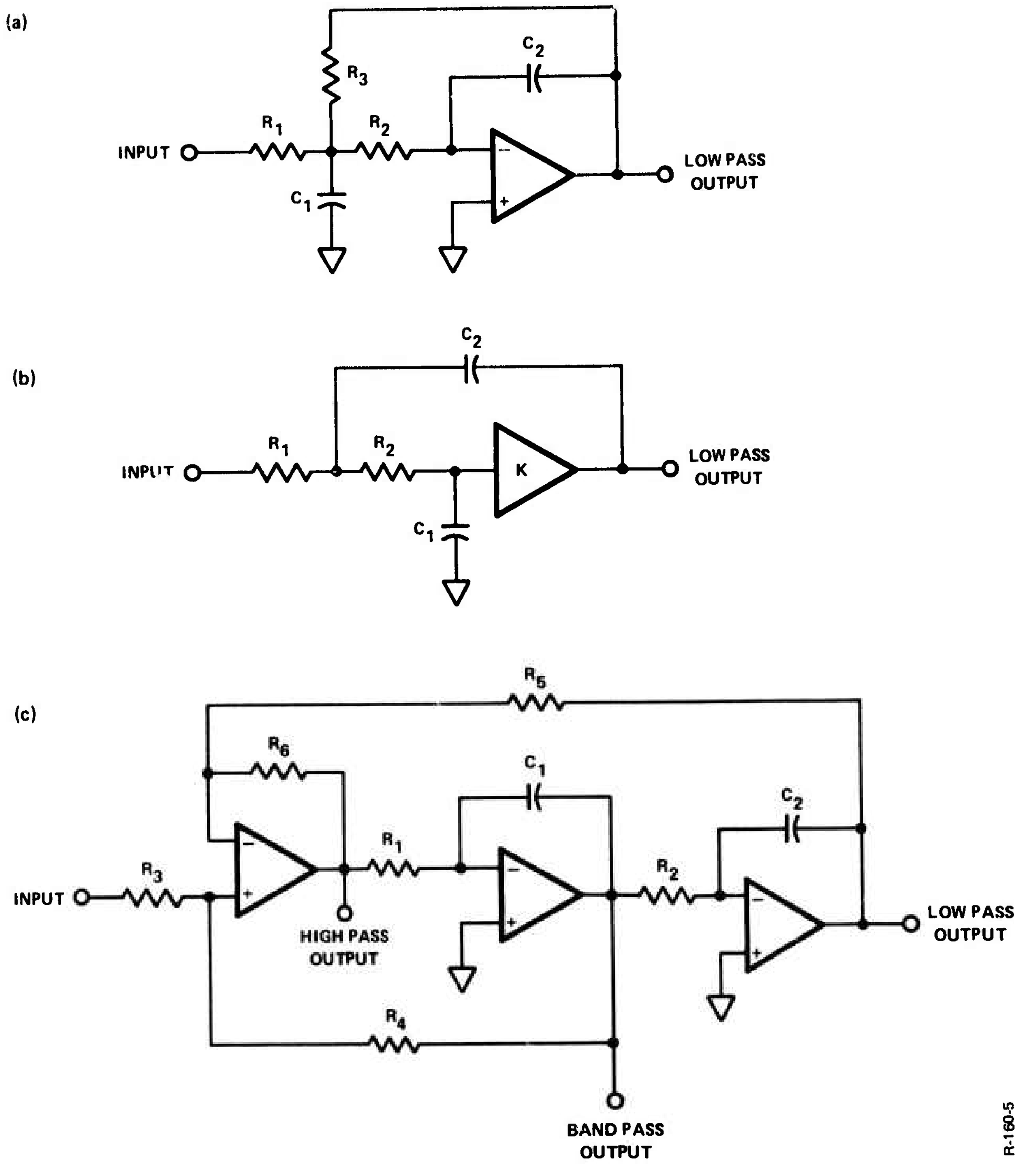


Figure 2-1 - Active Filter Forms

ented for the AS-11B-1, R_1 and R_2 are selected digitally from the control computer to control frequency. R_3 is either fixed or relay-selected to switch damping for 2-pole or 4-pole filter operation.

A tunable video filter system for the AS-11B-1 was designed using the basic filter section circuit of Figure 2-1(c). The filter system consists of two identical channels; one for photo 1 and the other for photo 2. Each channel has a total of four filter sections; two lowpass sections and two highpass sections. The lowpass sections determine the upper video cut-off frequency, and the highpass sections determine the lower video cut-off frequency. For 2-pole operation, only one highpass and one lowpass section are used in each channel. For 4-pole operation, filter sections are cascaded to form the more complex filters. Highpass and lowpass sections are cascaded to form the composite bandpass video filters. The highpass and lowpass sections can be tuned independently, providing a high degree of video filtering control. A detailed description of the tunable video filter hareware is presented in Section 3.1.

To control the operation of the tunable video filters, an AS-11B-1 frequency control program was developed. This program generates upper and lower filter control frequencies as a function of correlation. The frequency control functions can be modified by changing certain program constants to provide a variety of frequency control strategies. The frequency control program is described in Section 3.2, and strategy modifications are described in Appendix B.

The tunable video filter hardware and software were integrated with an AS-11B-1 automated stereoplotted system at Rome Air Development Center (RADC) and checked out. Correlator gains tests and automatic profiling tests were then performed using a variety of filter control strategies and filter configurations. These strategy optimization tests were performed using the Fort Sill 1:50,000 frame model. When sufficient experience had been obtained with the Fort Sill model, tests were performed using the California (Las Vegas) 1:200,000 frame model and two models which were supplied by RADC. One of the RADC models was a panoramic model of the Arizona area and the other was a frame model. For the Fort Sill model, plotting velocity and correlator gains tests were performed. For the California model and the two RADC models, profiling velocity and elevation accuracy evaluation tests were performed. A set of correlator gains was also run for the California model.

For the two RADC models, photographic plots of correlation and X parallax functions were made. These photographs show the effects of video filtering on correlation and parallax functions. To make these plots, the sweep output signal of an oscilloscope was applied to the X scan deflection of the photo 1 scanner. The vertical input of the oscilloscope was then connected to either the correlation or x parallax output of the correlator. The photo, therefore, shows correlation or parallax as a function of the relative X displacement between photo 1 and photo 2. An oscilloscope camera was used to record the correlation and parallax function traces. Multiple exposures were made using various filter cut-off frequencies. The plots, therefore, show families of correlation and parallax functions. Results of these experiments are discussed in the next subsection.

2.3 RESULTS AND CONCLUSIONS

No significant problems were encountered in implementing experimental adaptive bandpass tunable video filtering on the AS-11B-1 automated stereoplotter system. The experimental tunable video filter hardware performance was completely satisfactory for the AS-11B-1 requirements. Phase tracking error, the most critical requirement of the AS-11B-1 video filters, was less than 4 degrees over the entire operating range of the tunable filters. The filter control software functions provided stable closed-loop operation of the filter frequency control loop. Implementation of adaptive tunable video filtering on production AS-11B-1 systems could be achieved easily.

Results of the profiling tests are summarized in Figure 2-2. For the Fort Sill model, a total of seven runs were made. Although all the runs made with the tunable filters show an improvement over the normal filter run, the improvement is not dramatic. As can be seen for Fort Sill runs 3, 4, 6, and 7, the effect of using 4-pole filtering on the high end is insignificant. No profiling tests were made using 4-pole filtering on the low end because of certain problems experienced when using this configuration. In some instances, the system would not pull-in properly when 4-pole filtering was used for the low-end frequency. From these results, it can be concluded that 4-pole filtering is neither helpful nor desirable. This is important because the provision of 4-pole filter response doubles the number of filter sections which must be used to implement the filters.

For the California (Las Vegas) model, the profiling tests show a significant reduction in searches and assists when using the tunable filtering. The plotting speed and rms error differences are less dramatic. Automatic operation velocity, however, was significantly improved. In these tests, the tunable filtering allowed the system to plot areas which had to be skipped for the normal filter run. This was probably because of the increased correlation values obtained with tunable filtering. Because of this increased correlation, however, the system tended to continue plotting too far when lost before going into search. This implies that use of the tunable filters would require more system optimization to determine more suitable correlation thresholds and plotting strategies. It may be desirable to use different video filtering for the measurement of correlation than that which is used to measure parallax and slope.

Results of profiling tests with the RADC models were not dramatic. For the panoramic model, a slight improvement in manual-to-automatic rms elevation error was obtained with dynamic filter tuning. For the frame model, plotting speed was improved but more manual assistance was required. The increased manual assistance was probably due to the tendency to wander too far off the ground before going into search, making successful search less likely.

Correlator gains were measured over the Fort Sill and California models for various filter control strategies. Results of the correlator gains tests are summarized in Figure 2-3. For the Fort Sill model, variations in correlator gains were slight. For the California model, correlation was significantly higher with dynamic filter tuning when compared with results for the normal

MODEL		VIDEO FILTERING STRATEGY		PROFILING TEST RESULTS					
		LOW END FREQ. FL (kHz)	HIGH END FREQ. FH (kHz)	PLOTTING VELOCITY (MM/SEC)	AUTO. OP. VELOCITY (MM/SEC)	SEARCHES	ASSISTS	MANUAL EVALUATION (μM RMS)	AUTO EVALUATION (μM RMS)
FT. SILL	1.	NORMAL 32	NORMAL 150	2.17	1.94	--	--	--	--
	2.	VAR. 16-64, 2-POLE	VAR. 32-200, 2-POLE	2.23	2.02	--	--	--	--
	3.	FIXED 31.5, 2-POLE	VAR. 32-200, 2-POLE	2.27	2.04	--	--	--	--
	4.	FIXED 31.5, 2-POLE	VAR. 32-200, 4-POLE	2.30	2.07	--	--	--	--
	5.	FIXED 23.7, 2-POLE	VAR. 32-200, 4-POLE	2.34	2.11	--	--	--	--
	6.	VAR. 16-47, 2-POLE	VAR. 32-200, 2-POLE	2.36	2.12	--	--	--	--
	7.	VAR. 16-47, 2-POLE	VAR. 32-200, 4-POLE	2.35	2.12	--	--	--	--
CALIFORNIA (LAS VEGAS)	1.	NORMAL 32	NORMAL 150	0.94	0.63	37	14	60.9	23.0
	2.	FIXED 31.5, 2-POLE	VAR. 64-128, 2-POLE	1.04	0.92	9	2	58.0	25.4
	3.	VAR. 16-47, 2-POLE	VAR. 64-128, 2-POLE	1.22	1.10	4	2	--	--
RADC PAN. ARIZONA	1.	FIXED 31.5, 2-POLE	FIXED 151.2, 2-POLE	2.32	1.88	0	0	23.0	10.6
	2.	VAR. 16-47, 2-POLE	VAR. 32-200, 2-POLE	2.39	1.89	0	0	19.6	10.8
RADC FRAME	1.	FIXED 31.5, 2-POLE	FIXED 151.2, 2-POLE	1.85	1.20	18	5	33.3	25.2
	2.	VAR. 16-47, 2-POLE	VAR. 64-128, 2-POLE	2.14	1.57	11	10	32.1	29.1

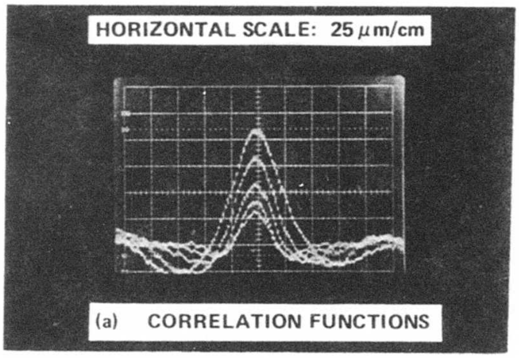
R-160-5

Figure 2-2 - Tunable Video Filter Profiling Test Summary

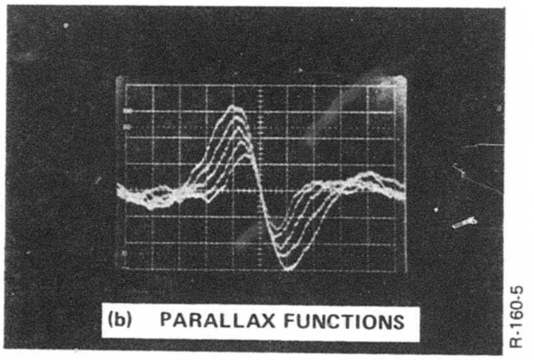
MODEL	VIDEO FILTERING STRATEGY		AVERAGE OUTPUTS				
	LOW END FREQ. FL (kHz)	HIGH END FREQ. FH (kHz)	CORRELATION	PX GAIN	PY GAIN	SX GAIN	SY GAIN
FORT SILL	NORMAL 32	NORMAL 150	48.0	0.922	0.759	0.884	1.264
	VAR. 16-64, 2-POLE	VAR. 32-200, 2-POLE	47.2	0.935	0.784	1.010	1.330
	VAR. 16-64, 4-POLE	VAR. 32-200, 4-POLE	47.4	0.945	0.862	0.786	1.304
	FIXED 31.5, 2-POLE	VAR. 32-200, 4-POLE	49.2	0.976	0.787	0.784	1.176
	FIXED 23.7, 2-POLE	VAR. 32-200, 4-POLE	50.5	0.961	0.735	0.697	1.013
	VAR. 16-47, 2-POLE	VAR. 32-200, 2-POLE	48.4	0.924	0.711	0.852	1.165
CALIFORNIA (LAS VEGAS)	NORMAL 32	NORMAL 150	33.2	0.647	0.331	0.533	0.639
	FIXED 31.5, 2-POLE	VAR. 64-128, 2-POLE	43.3	0.521	0.146	0.223	0.219

R-160-5

Figure 2-3 - Tunable Video Filter Correlator Gains



(a) CORRELATION FUNCTIONS



(b) PARALLAX FUNCTIONS

Figure 2-4 - Effects of Low-End Filter Frequency (FL) on Correlation and Parallax for FL = 16, 28.4, 40.8, 53.2, and 64 kHz filters. Correlator gains, however, were significantly lower with dynamic frequency control. This was probably due to the generally smaller scan size resulting from increased correlation. Average scan size for the normal filters was about 0.67 of maximum (maximum = 5 millimeters) and for the dynamically tuned filters was about 0.39 of maximum. Use of a larger scan size strategy than is presently available would probably correct the problem.

Representative plots of correlation and parallax functions appear in Figures 2-4, 2-5, and 2-6. All of these plots were made while scanning a fairly good image of mesquite bushes in the RADC panoramic model. A scan size of 500 μm (D = 0.1) was used for the plots. Figure 2-4 shows the effects of varying the low-end video filter cut-off frequency. As the cut-off frequency is reduced from 64 kHz to 16 kHz, the correlation and parallax functions became broader and higher in peak amplitude. Reducing the low-end cut-off frequency, therefore, increases pull-in range, tracking range, and correlation. The increased pull-in and tracking range results from the lower video frequencies used in computing the parallax function. The increased correlation is due to the higher spectral content at low frequencies, a characteristic exhibited by most aerial photographic images. The video frequency range of 16 to 64 kHz corresponds to a spatial frequency range of about 3.5 to 14 cycles/millimeter in the photograph.

Figure 2-5 shows the effects of varying the high-end video filter cut-off frequency. As the cut-off frequency is reduced from 200 kHz to 32 kHz, the general shape of the correlation and parallax functions do not change significantly but their amplitude increases. The increased amplitude results from the rejection of high frequency noise in the upper region of the video spectrum where little signal information is present. The video frequency range of 32 to 200 kHz corresponds to a spatial frequency range of about 7 to 45 cycles/millimeter in the photograph.

For the plots of Figure 2-6, the low-end filter elements were changed to cover the range of 32 to 128 kHz. The high-end cut-off frequency was fixed at 200 kHz. As the low-end frequency is increased, the correlation and parallax functions decrease in amplitude (also in pull-in range, etc.). The plots show that the signal information above about 100 kHz contributes very little to correlation and parallax outputs. This indicates that there is little useful information in the photographic image above a frequency of about 22 cycles/millimeter.

2.4 RECOMMENDATIONS

Adaptive tunable video filtering can be of significant value in reducing searching and manual assistance for poor photographic input materials such as the California model. If adaptive filtering is implemented, reoptimization of scan size strategy, correlation thresholds, and possibly plotting velocity control strategies should be performed. Because of the generally increased correlation obtained with adaptive filtering over the California model, scan size was reduced too much with the presently available scan size strategies. Different strategies should therefore be developed. The increased correlation also tended to allow the system to plot when lost. Correlation thresholds and perhaps velocity functions should be reoptimized to correct for this.

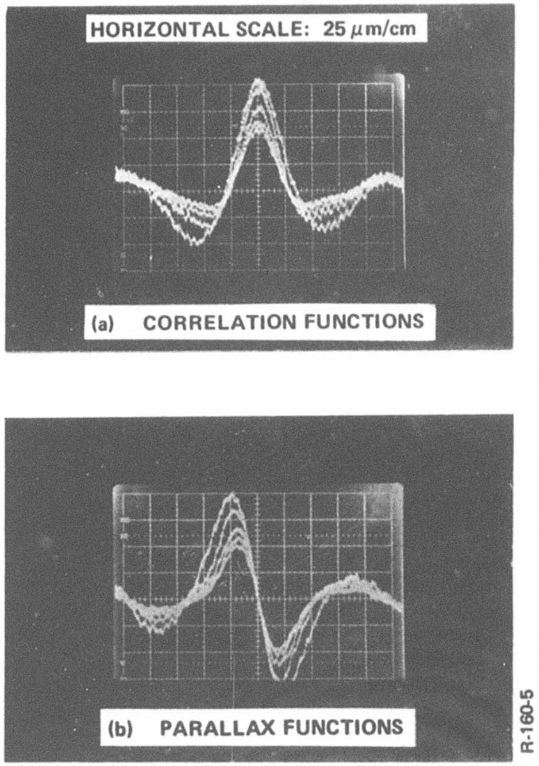


Figure 2-5 - Effects of High-End Filter Frequency (FH) on Correlation and Parallax for FH = 32, 75.4, 118.7, 162.1, and 200 kHz

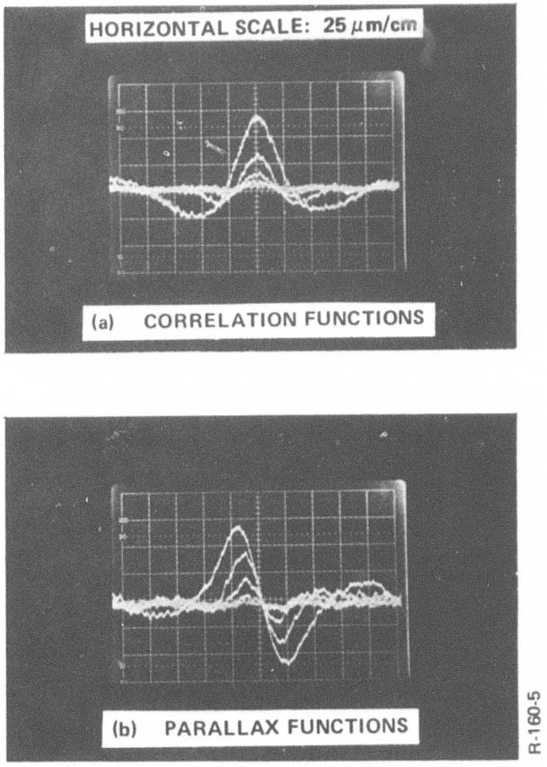


Figure 2-6 - Effects of Low-End Filter Frequency (FL) on Correlation and Parallax for FL = 32, 56.8, 81.5, 106.3, and 128 kHz

It may also be advantageous to use different video filtering for the measurement of correlation than is used for measurement of parallax. Correlation should be based more on matching of medium and high frequency image content rather than low frequency content. Low frequency content is more useful for extending parallax pull-in and tracking ranges. Implementation of tunable video filtering should provide different video filtering for correlation and parallax measurement.

For production units, the filters should be 2-pole rather than 4-pole. The 4-pole filter response did not significantly improve performance when used at the high-end filter cut-off frequency, and actually caused some pull-in problems when used at the low-end filter cut-off frequency. These results and the fact that 4-pole filters require much more hardware to implement, make 2-pole filtering the clear choice.

SECTION 3

EXPERIMENTAL AS-11B-1 TUNABLE VIDEO FILTER SYSTEM

This section describes the experimental hardware and software developed on the Adaptive Bandpass Tunable Filter project to implement experimental adaptive video filtering on the AS-11B-1 automated analytical stereoplotter. The first subsection describes the breadboard tunable video filter hardware. The second subsection describes the experimental software for computer control of the filter.

3.1 HARDWARE DESCRIPTION

The tunable video filter hardware consists of two identical filters and interface logic to provide computer control of filter cut-off frequencies. One of the filters processes photo 1 video, and the other processes photo 2 video. Each filter consists of a highpass filter and a lowpass filter cascaded to form a bandpass filter. The cut-off frequencies of the highpass and lowpass filters are controlled independently either automatically from the AS-11B-1 control computer or manually with a set of toggle switches on the video filter front panel. The highpass or lowpass filters in the two video channels are tuned in unison to ensure identical processing of photo 1 and photo 2 video. The filter constants are adjusted to give a Butterworth or maximally flat amplitude characteristic. Other filter types such as RC or Bessel can be implemented by changing circuit component values.

A system diagram of the tunable video filter is shown in Figure 3-1. The filter is composed of elemental second-order filter sections which can be configured to provide either 2-pole or 4-pole response at each cut-off frequency. There are eight such sections in the filter: four for photo 1 and four for photo 2. For 2-pole response, each cut-off frequency of the filter is determined by a single second-order filter section. For 4-pole response, two 2-pole sections are cascaded for each filter cut-off frequency. Switching from 2-pole to 4-pole response is accomplished by switching inputs to the second filter section of a cascaded pair. For 2-pole operation, the input video is applied directly to the second filter section. For 4-pole operation, the video passes through the first filter section before entering the second filter section. The 2-pole and 4-pole operations require different damping constants for the second filter section. This requisite change in damping is also accomplished by input switching to the second section. The 2-pole and 4-pole operations can be selected independently for the highpass and lowpass filters, using toggle switches on the tunable video filter control panel. Video inputs and outputs of the tunable video filter are buffered by video line receivers and video line drivers.

The basic second-order filter section used in the tunable video filter is a state-variable type active filter. A simplified circuit diagram of this filter is shown in Figure 3-2. The circuit uses three operational amplifiers and provides simultaneous highpass, lowpass, and bandpass outputs. What makes this particular circuit desirable for the tunable video filter is that the tuning resistors R1 and R2 are connected to outputs of operational amplifiers.

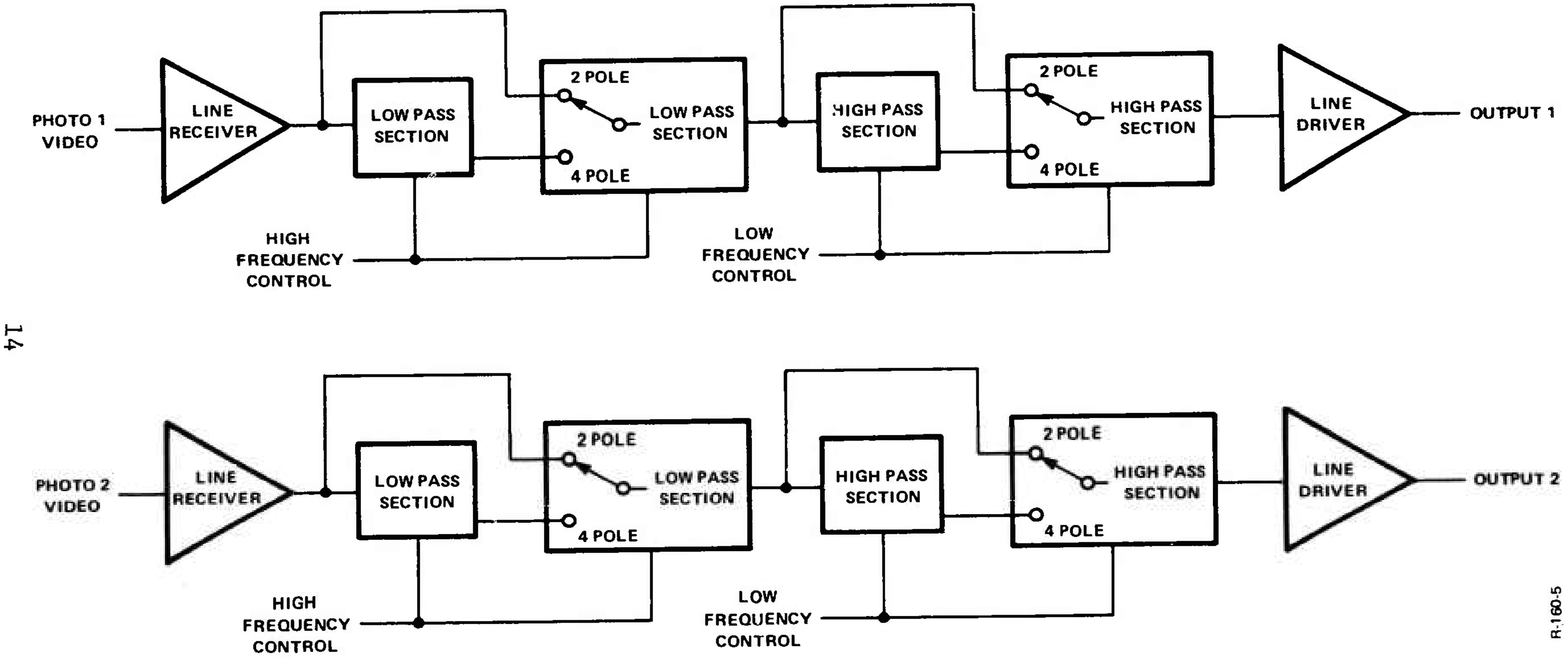


Figure 3-1 - Tunable Video Filter System

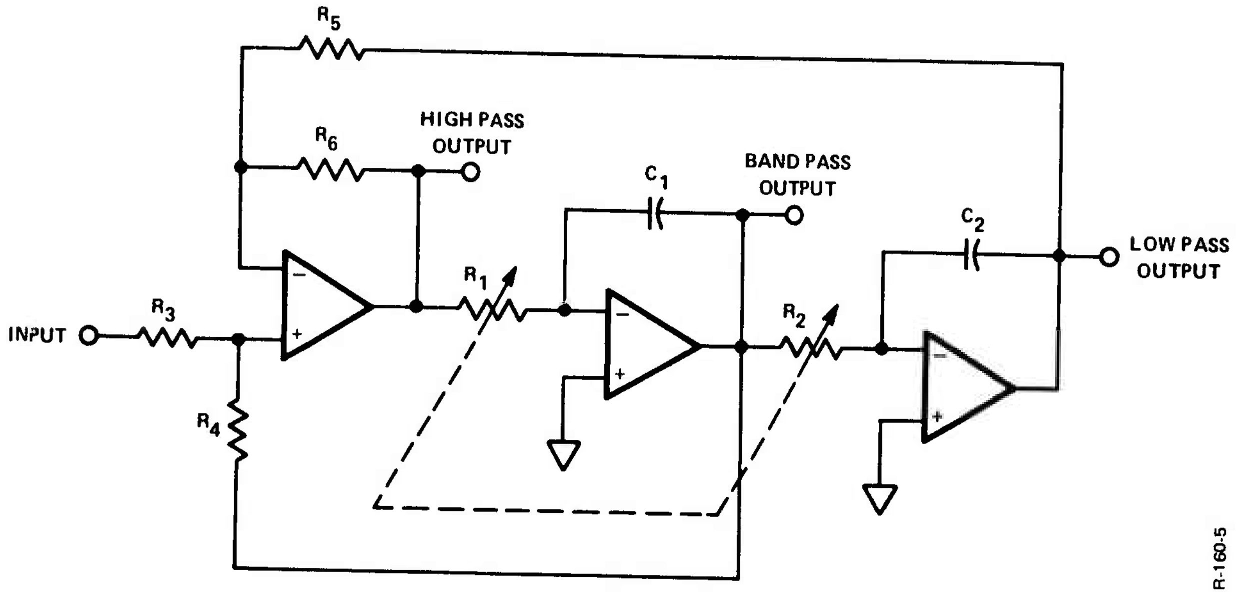


Figure 3-2 - State Variables Active Filter

This allows the use of junction field effect transistor (FET) switches in the tuning networks since the FET gates can be referred to the low impedance operational amplifier output. The lowpass transfer function of this circuit is

$$T_L(s) = \frac{H_L\ \omega_o^2}{s^2 + s\ \alpha\ \omega_o + \omega_o^2}$$

where

$$H_L = \frac{1 + R5/R6}{1 + R3/R4}$$

$$\omega_o = \left(\frac{R6}{R5\ R1\ C1\ R2\ C2}\right)^{1/2}$$

$$\alpha = \frac{1 + R6/R5}{1 + R4/R3}\left(\frac{R5\ R2\ C2}{R6\ R1\ C1}\right)^{1/2}$$

The transfer function for the highpass output is

$$T_H(s) = \frac{H_H\ s^2}{s^2 + s\ \alpha\ \omega_o + \omega_o^2}$$

where

$$H_H = \frac{1 + R6/R5}{1 + R3/R4}$$

From these relationships it can be seen that the cut-off frequency ω_o can be tuned without affecting gain (H) or damping (α) by varying R1 and R2 in unison. In the tunable video filter, R1 and R2 are composed of parallel resistor combinations which are switched by FET transistors to achieve dynamic control of ω_o. It can also be seen from the above relationships that the damping constant α can be changed without affecting frequency by changing R3. In the tunable video filter, R3 is switched to obtain different damping when switching between 2-pole and 4-pole operations. The gain of the filter also changes when R3 is changed, but this is of no consequence in the AS-11B-1 system since the video is subsequently limited in the video processor.

Digital computer control of the tunable video filter is accomplished by utilizing a spare correlator data channel of the AS-11B-1 system. Frequency data is transferred from the accumulator to a special interface logic card which was added to the AS-11B-1 correlator hardware. The data consists of five frequency data bits and two control bits. The control bits determine whether the frequency data is for the highpass filters or the lowpass filters. The logic on the special interface card examines the control bits and routes the data to the appropriate buffers. These data buffers normally control the FET switches of the filters through FET drivers.

A switch is provided on the front panel of the tunable video filter, which allows manual control of the filter frequencies. When this switch is in the MANUAL position, filter frequencies are determined by 10 toggle switches on the front panel. This provides a convenient way of checking filter operation, and allows the filter to be operated with fixed cut-off frequencies without having to change computer programs. In addition to these manual control switches, the front panel contains indicator lights which display upper and lower cut-off frequencies during both manual and automatic operation of the filter.

Figure 3-3 shows typical frequency domain amplitude responses of the filters. The full scale range of these plots is about 280 kHz. Figures 3-3(a) and (b) show amplitude responses for a moderately narrow filter bandwidth with a lower cut-off frequency of 40 kHz and an upper cut-off frequency of 120 kHz. Plot (a) shows 2-pole response and (b) shows 4-pole response. Note that the edges of the passband are steeper and more clearly defined in the 4-pole response. Figures 3-3(c) and (d) show 2- and 4-pole amplitude responses respectively for maximum filter bandwidth. In these plots, the lower cut-off frequency is 16 kHz and the upper cut-off frequency is 200 kHz.

Since the detection of parallax is essentially a phase detection process, it is important that the phase shift of the two filters (photo 1 and photo 2) track fairly well over the entire frequency range. This is particularly important at the low frequencies since low frequency phase shifts correspond to

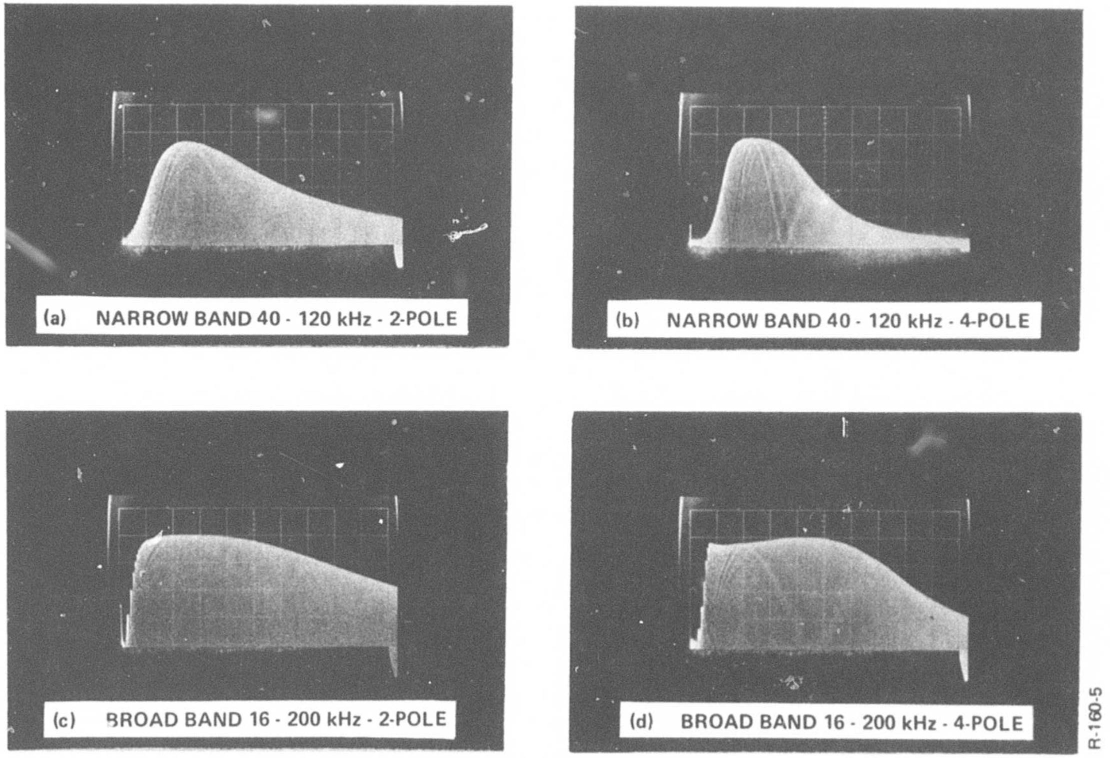


Figure 3-3 - Tunable Video Filter Amplitude Responses

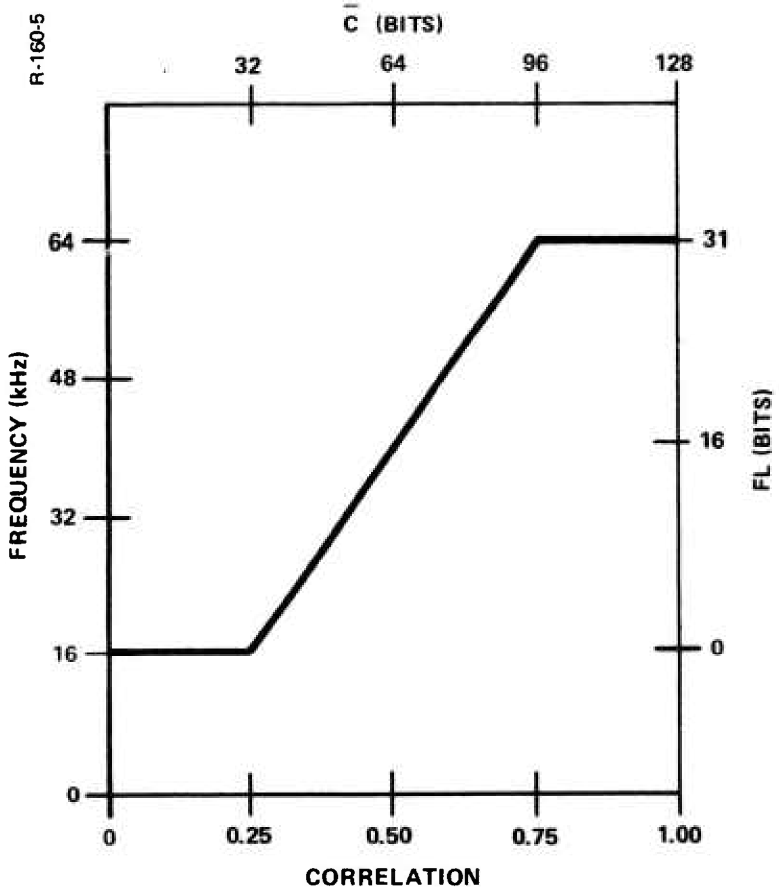


Figure 3-4 - Basic Low Frequency Control Strategy

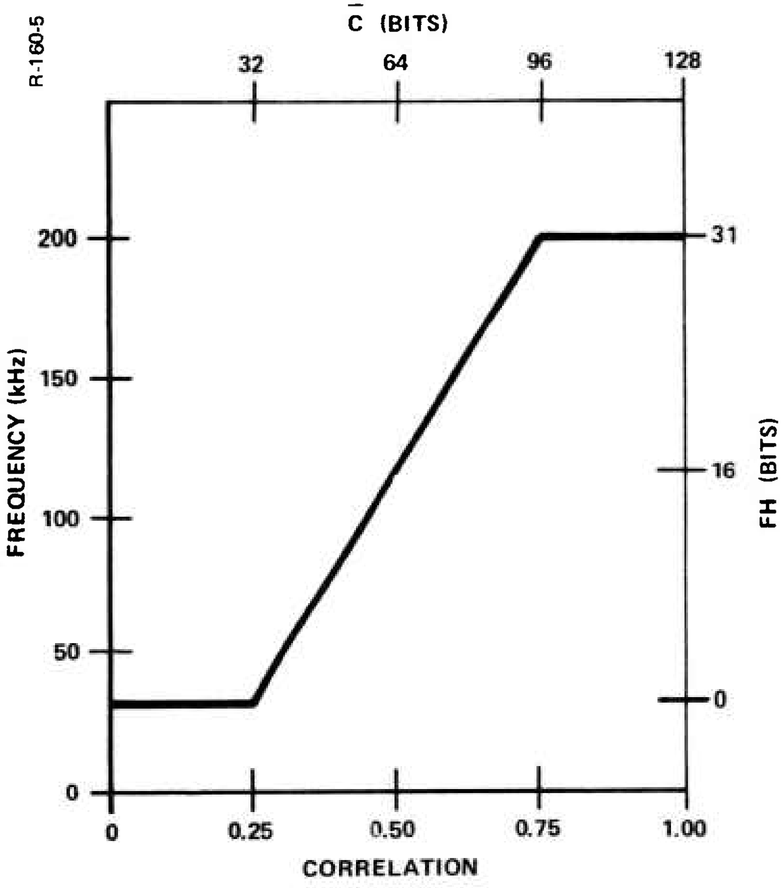


Figure 3-5 - Basic High Frequency Control Strategy larger parallaxes or time shifts than high frequency phase shifts. It is not essential that the phase tracking be exact because the periodic reversal of the scan direction causes filter phase tracking errors to cancel, but large phase tracking errors will reduce parallax gains. The gain reduction due to phase tracking error is not too significant, however, since an error of about 25 degrees would be required to reduce the gain by 10 percent. The maximum measured phase tracking error of the tunable video filters was about 4 degrees, corresponding to a gain reduction of about 0.25 percent at one particular frequency. Over most of the frequency range, the phase tracking error was imperceptible.

3.2 FREQUENCY CONTROL PROGRAM

3.2.1 Program Function and Operation

The Frequency Control Program operates in conjunction with other AS-11B-1 programs to control the upper and lower cut-off frequencies of the tunable video filter during automatic operation. It essentially computes upper and lower filter cut-off frequencies as a function of correlation, and outputs the frequency data to the tunable video filter 50 times per second. The program therefore dynamically controls filter frequencies during automatic plotting and other automatic operations.

There are three versions of the Frequency Control Program. Each version operates in conjunction with one of the three system modes: setup, profiling, or contouring. After one of these system mode programs has been loaded, the appropriate Frequency Control Program is loaded by placing the program tape in the tape reader and depressing the READ TAPE pushbutton.

Strategy modification tapes are also available for altering the basic frequency control strategy. The strategy modifications are discussed in Appendix B. Strategy modification tapes are read after one of the frequency control program tapes has been read.

3.2.2 Program Description

The Frequency Control Program generates two separate frequency control functions for the tunable video filter. One of these functions is used to control the upper cut-off frequency of the filter, and the other is used to control the lower cut-off frequency. Each function is of the general form

$$F(I) = \begin{cases} F1(I), & \bar{C} < C1(I) \\ [\bar{C} - C1(I)]\, M(I) + F1(I), & C1(I) < \bar{C} < C2(I) \\ F2(I), & \bar{C} > C2(I) \end{cases}$$

A single computer routine is used to implement this function, and the index I determines whether the upper or lower cut-off frequency is being computed.

The particular frequency functions (strategies) implemented in the program are shown in Figures 3-4 and 3-5. Below some lower correlation value C1(I) the frequency is fixed at some minimum value F1(I). When correlation increases above C1(I), frequency increases linearly with correlation. Above some upper correlation value C2(I) the frequency is fixed at some maximum value F2(I). These functions may be altered by changing the constants C1(I), C2(I), F1(I), F2(I), and a slope constant M(I). This can be accomplished by preparing a change tape according to the format shown in Figure 3-6.

A flow chart of the Frequency Control Program is shown in Figure 3-7, and assembly listings are shown in Figures 3-8, 3-9, and 3-10. The program is entered from the normal 50 per second programs at statement label SCAN. The index I is set to zero for the first pass through the program. Average correlation is picked up from location 245 (octal) at a scaling of S7. The lower cut-off filter frequency is then computed as a 5-bit quantity with a scaling of S2. A control bit is then added in position 9 to indicate lower cut-off frequency, and bits 3 through 10 are transmitted to the tunable video filter. On the second pass through the program, the index I is set to 1, and the upper cut-off frequency is computed. A control bit is added in position 10 to indicate upper cut-off frequency, and bits 3 through 10 are again transmitted to the tunable video filter. After executing the second pass through the program, control is returned to the normal AS-11B-1 50 per second programs at SCAN + 6.

Filter frequency data is transferred from the computer to the video filter via the gate size (D') correlator hybrid multiplier channel. This channel is not used in the normal AS-11B-1 system. Interpretation of control bits 9 and 10, and routing of the high and low frequency data to the appropriate data buffers, is performed by logic in the tunable video filter hardware.

A list of constants and variables used in the Frequency Control Program appears in Table 3-1. This table shows the octal locations of constants, the source location of the variable $\bar{C}$,internal scaling of constants and variables, and nominal values loaded by the program tapes.

DATA ITEM	TAPE FORMAT
---	SOM (CONTROL A) B
---	333P
C2L	D96S7M
C2H	D96S7M
C1L	D32S7M
C1H	D32S7M
ML	7600M
MH	7600M
F2L	D31S2M
F2H	D31S2M
F1L	D0S2M
F1H	D0S2M
---	4104PG
---	EOT (CONTROL D)

R-160-5

Figure 3-6 - Change Tape Format

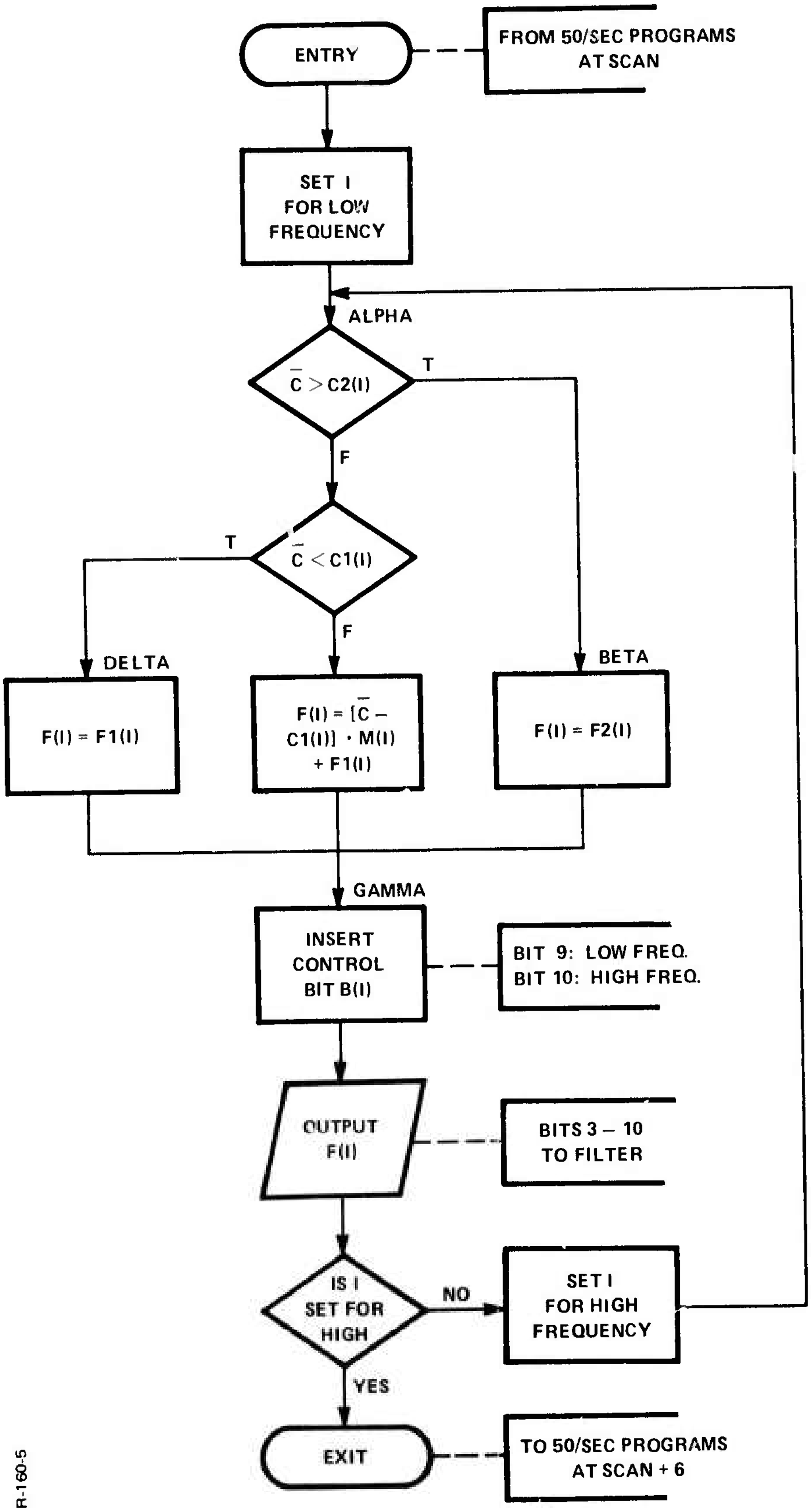


Figure 3-7 – Frequency Control Program

```
12270 012270                 ORG    '12270              SET UP MODE
12270 044275(12275)          J      ENTRY
12271 000000                 FIX    0
12272 000000                 FIX    0
12273 000000                 FIX    0
12274 034000          IADR   FIX    '34000
12275 074274(12274)ENTRY     JM*    IADR                GO TO FREQ FN
00333 000333                 ORG    '333                FILTER FUNCTION
00333 030000          C2     FIX    '30000              C2L 96 BITS S7
00334 030000                 FIX    '30000              C2H 96 BITS S7
00335 010000          C1     FIX    '10000              C1L 32 BITS S7
00336 010000                 FIX    '10000              C1H 32 BITS S7
00337 007600          M      FIX    '7600               SLOPE .484375
00340 007600                 FIX    '7600               SLOPE .484375
00341 000174          F2     FIX    '174                F2L 31 BITS S2
00342 000174                 FIX    '174                F2H 31 BITS S2
00343 000000          F1     FIX    0                   F1L 0 BITS S2
00344 000000                 FIX    0                   F1H 0 BITS S2
00345 000400          B      FIX    '400                LF OUTPUT BIT
00346 001000                 FIX    '1000               HF OUTPUT BIT
00347 000000          F      RESZ   1                   LOW FREQ S2
00350 000000                 RESZ   1                   HIGH FREQ S2
00351 000245          CBAR   EQU    '245
34000 034000                 ORG    '34000              FILTER FUNCTION
34000 000000          RTRN   RESZ   1                   RETURN ADR.
34001 764400          FLTR   CL1                        SET X1 FOR LF
34002 240245(00245)ALPHA     LDA    CBAR                LOAD CORR.
34003 625333(00333)          CMPR   C2,1                C:C2
34004 776607                 JTG    BETA                JUMP IF C.G.C2
34005 225335(00335)          SBA    C1,1                C-C1
34006 770207                 JAL    DELTA               JUMP IF C.L.C1
34007 764102                 TRAQ                       C-C1 TO Q
34010 764200                 CLA                        CLEAR A
34011 405337(00337)          MPY    M,1                 (C-C1)M
34012 205343(00343)          ADA    F1,1                (C-C1)M+F1
34013 044017(34017)          J      GAMMA               GO TO GAMMA
34014 245341(00341)BETA      LDA    F2,1                SET F=F2
34015 044017(34017)          J      GAMMA               GO TO GAMMA
34016 245343(00343)DELTA     LDA    F1,1                SET F=F1
34017 505345(00345)GAMMA     OR     B,1                 INSERT CNTRL. BIT
34020 265347(00347)          STA    F,1                 STORE OUTPUT F
34021 701321          SIGMA  LWRD   '701321             TEST READY
34022 044021(34021)          J      SIGMA               NOT READY
34023 700602                 LWRD   '700602             OUTPUT F
34024 767401                 SBC1   1                   TEST FOR
34025 777203                 JTE    EXIT                SECOND PASS
34026 764400                 CL1                        SET X1 FOR
34027 766401                 ADC1   1                   SECOND PASS (HF)
34030 044002(34002)          J      ALPHA               GO TO ALPHA
34031 054000(34000)EXIT      J*     RTRN                RETURN JUMP
34032 004104                 END    '4104
ALPHA   34002       B       00345       BETA    34014       CBAR    00245
 C1     00335       C2      00333        DELTA  34016        ENTRY  12275
 EXIT   34031       F       00347        FLTR  *34001        F1     00343
 F2     00341       GAMMA   34017        IADR   12274        M      00337
 RTRN   34000       SIGMA   34021
 ***000 ERRORS**000 WARNINGS***
END
```

Figure 3-8 - Assembly Listings for Set-Up Mode

R-160-5

```
                                  ORG    '13555         PROFILE MODE
13555 013555
13555 044562(13562)               J      ENTRY
13556 000000                      FIX    0
13557 000000                      FIX    0
13560 000000                      FIX    0
13561 034000             IADR     FIX    '34000
13562 074561(13561)ENTRY          JM*    IADR           GO TO FREQ FN
                                  ORG    '333           FILTER FUNCTION
00333 000333
00333 030000             C2       FIX    '30000         C2L 96 BITS S7
00334 030000                      FIX    '30000         C2H 96 BITS S7
00335 010000             C1       FIX    '10000         C1L 32 BITS S7
00336 010000                      FIX    '10000         C1H 32 BITS S7
00337 007600             M        FIX    '7600          SLOPE .484375
00340 007600                      FIX    '7600          SLOPE .484375
00341 000174             F2       FIX    '174           F2L 31 BITS S2
00342 000174                      FIX    '174           F2H 31 BITS S2
00343 000000             F1       FIX    0              F1L 0 BITS S2
00344 000000                      FIX    0              F1H 0 BITS S2
00345 000400             B        FIX    '400           LF OUTPUT BIT
00346 001000                      FIX    '1000          HF OUTPUT BIT
00347 000000             F        RESZ   1              LOW FREQ S2
00350 000000                      RESZ   1              HIGH FREQ S2
00351 000245             CBAR     EQU    '245
                                  ORG    '34000         FILTER FUNCTION
34000 034000
34000 000000             RTRN     RESZ   1              RETURN ADR.
34001 764400             FLTR     CLI                   SET X1 FOR LF
34002 240245(00245)ALPHA          LDA    CBAR           LOAD CORR.
34003 625333(00333)               CMPR   C2,1           C:C2
34004 776607                      JTG    BETA           JUMP IF C.G.C2
34005 225335(00335)               SBA    C1,1           C-C1
34006 770207                      JAL    DELTA          JUMP IF C.L.C1
34007 764102                      TRAQ                  C-C1 TO Q
34010 764200                      CLA                   CLEAR A
34011 405337(00337)               MPY    M,1            (C-C1)M
34012 205343(00343)               ADA    F1,1           (C-C1)M+F1
34013 044017(34017)               J      GAMMA          GO TO GAMMA
34014 245341(00341)BETA           LDA    F2,1           SET F=F2
34015 044017(34017)               J      GAMMA          GO TO GAMMA
34016 245343(00343)DELTA          LDA    F1,1           SET F=F1
34017 505345(00345)GAMMA          OR     B,1            INSERT CNTRL. BIT
34020 265347(00347)               STA    F,1            STORE OUTPUT F
34021 701321             SIGMA    LWRD   '701321        TEST READY
34022 044021(34021)               J      SIGMA          NOT READY
34023 700602                      LWRD   '700602        OUTPUT F
34024 767401                      SBC1   1              TEST FOR
34025 777203                      JTE    EXIT           SECOND PASS
34026 764400                      CL1                   SET X1 FOR
34027 766401                      ADC1   1              SECOND PASS (HF)
34030 044002(34002)               J      ALPHA          GO TO ALPHA
34031 054000(34000)EXIT           J*     RTRN           RETURN JUMP
34032 004104                      END    '4104
ALPHA   34002        B        00345      BETA    34014       CBAR    00245
C1      00335        C2       00333      DELTA   34016       ENTRY   13562
EXIT    34031        F        00347      FLTR   *34001       F1      00343
F2      00341        GAMMA    34017      IADR    13561       M       00337
RTRN    34000        SIGMA    34021
***000 ERRORS**000 WARNINGS***
END
```

R-160-5

Figure 3-9 - Assembly Listings for Profile Mode

```
13516 013516                   ORG   '13516          CONTOUR MODE
13516 044523(13523)            J     ENTRY
13517 000000                   FIX   0
13520 000000                   FIX   0
13521 000000                   FIX   0
13522 034000             IADR  FIX   '34000
13523 074522(13522)ENTRY       JM*   IADR            GO TO FREQ FN
00333 000333                   ORG   '333            FILTER FUNCTION
00333 030000             C2    FIX   '30000          C2L 96 BITS S7
00334 030000                   FIX   '30000          C2H 96 BITS S7
00335 010000             C1    FIX   '10000          C1L 32 BITS S7
00336 010000                   FIX   '10000          C1H 32 BITS S7
00337 007600             M     FIX   '7600           SLOPE .484375
00340 007600                   FIX   '7600           SLOPE .484375
00341 000174             F2    FIX   '174            F2L 31 BITS S2
00342 000174                   FIX   '174            F2H 31 BITS S2
00343 000000             F1    FIX   0               F1L 0 BITS S2
00344 000000                   FIX   0               F1H 0 BITS S2
00345 000400             B     FIX   '400            LF OUTPUT BIT
00346 001000                   FIX   '1000           HF OUTPUT BIT
00347 000000             F     RESZ  1               LOW FREQ S2
00350 000000                   RESZ  1               HIGH FREQ S2
00351 000245             CBAR  EQU   '245
34000 034000                   ORG   '34000          FILTER FUNCTION
34000 000000             RTRN  RESZ  1               RETURN ADR.
34001 764400             FLTR  CLI                   SET X1 FOR LF
34002 240245(00245)ALPHA       LDA   CBAR            LOAD CORR.
34003 625333(00333)            CMPR  C2,1            C:C2
34004 776607                   JTG   BETA            JUMP IF C.G.C2
34005 225335(00335)            SBA   C1,1            C-C1
34006 770207                   JAL   DELTA           JUMP IF C.L.C1
34007 764102                   TRAQ                  C-C1 TO Q
34010 764200                   CLA                   CLEAR A
34011 405337(00337)            MPY   M,1             (C-C1)M
34012 205343(00343)            ADA   F1,1            (C-C1)M+F1
34013 044017(34017)            J     GAMMA           GO TO GAMMA
34014 245341(00341)BETA        LDA   F2,1            SET F=F2
34015 044017(34017)            J     GAMMA           GO TO GAMMA
34016 245343(00343)DELTA       LDA   F1,1            SET F=F1
34017 505345(00345)GAMMA       OR    B,1             INSERT CNTRL. BIT
34020 265347(00347)            STA   F,1             STORE OUTPUT F
34021 701321             SIGMA LWRD  '701321         TEST READY
34022 044021(34021)            J     SIGMA           NOT READY
34023 700602                   LWRD  '700602         OUTPUT F
34024 767401                   SBC1  1               TEST FOR
34025 777203                   JTE   EXIT            SECOND PASS
34026 764400                   CL1                   SET X1 FOR
34027 766401                   ADC1  1               SECOND PASS (HF)
34030 044002(34002)            J     ALPHA           GO TO ALPHA
34031 054000(34000)EXIT        J*    RTRN            RETURN JUMP
34032 004104                   END   '4104
ALPHA  34002      B      00345      BETA   34014      CBAR   00245
C1     00335      C2     00333      DELTA  34016      ENTRY  13523
EXIT   34031      F      00347      FLTR  *34001      F1     00343
F2     00341      GAMMA  34017      IADR   13522      M      00337
RTRN   34000      SIGMA  34021
***000 ERRORS**000 WARNINGS***
END
```

Figure 3-10 - Assembly Listings for Contour Mode

Table 3-1 - List of Constants and Variables

Constant/Variable	Octal Location	Scaling	Nominal Value
$\bar{C}$	245	S7	variable
F(L) Output	347	S2	variable
F(H) Output	350	S2	variable
C1L	335	S7	32
C1H	336	S7	32
C2L	333	S7	96
C2H	334	S7	96
ML	337	S13	0.484375
MH	338	S13	0.484375
F1L	343	S2	0
F1H	344	S2	0
F2L	341	S2	31
F2H	342	S2	31

R-160-5

APPENDIX A

DIGITAL FILTERS

During the design phase of the tunable filter project, consideration was given to the use of digital filters to implement adaptive bandpass tunable filters for the AS-11B-1. It was determined that digital filters are not suitable for the AS-11B-1 video filtering application primarily because of their limited speed and their extreme complexity. This appendix presents some background on digital filters and the rationale for not using digital filters for the AS-11B-1 tunable video filter.

Digital filters are essentially devices which process sampled data digitally to achieve some desired filtering effect. They can consist of special real-time digital processing hardware, or can simply be computer programs which implement digital filtering of a stored data set. The particular implementation used depends primarily on the speed at which data must be processed.

There are two basic types of digital filters commonly used. One is the transversal filter and the other is the recursive filter. The transversal filter is more flexible in the types of filtering which can be performed, but it is generally more expensive to fabricate. The transversal filter, in general, performs the following computation:

$$y_i = \sum_{k=0}^{N} h_k \, x_{i+k}$$

In this relationship, x_{i+k} are the input samples, y_i are the filter values, and h_k are the filter weights. The above relationship is the digital equivalent form of

$$y(t) = \int_{-\infty}^{\infty} h(\tau) \, x(t + \tau) \, d\tau$$

which is the convolution integral for time continuous filtering. A system diagram of the transversal filter is shown in Figure A-1. The blocks containing z^{-1} are essentially unit delay elements which delay the digital sample values by one sample. The filter must be capable of storing N input sample values in these delay elements, and must be capable of performing the N + 1 multiplications for each output sample value, y_i. This is not difficult for a digital computer to do if speed is not important, but real-time hardware for performing these functions would be considerable.

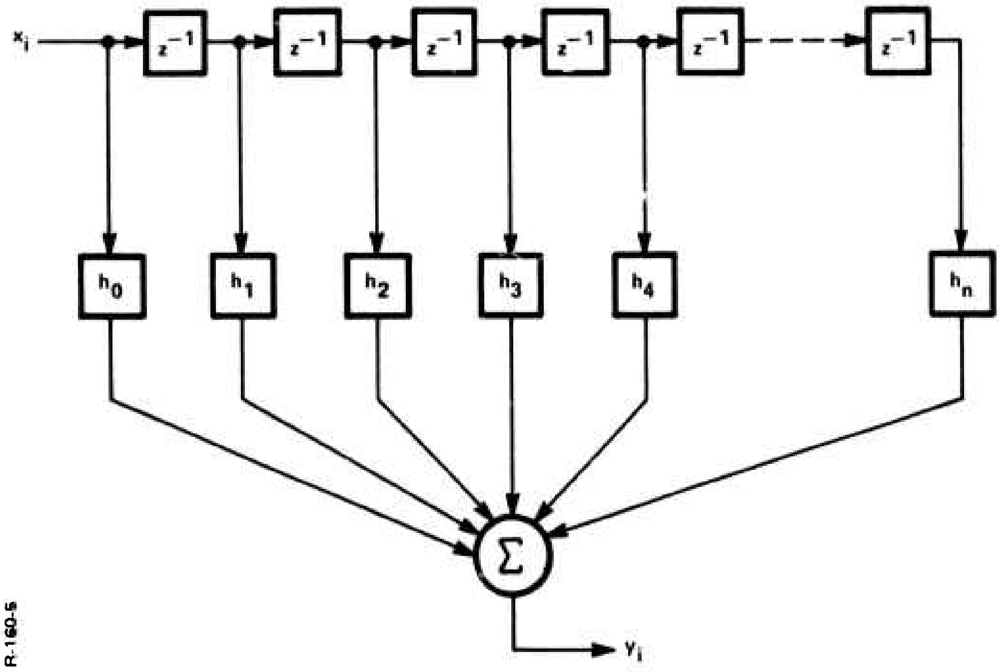


Figure A-1 - Transversal Filter

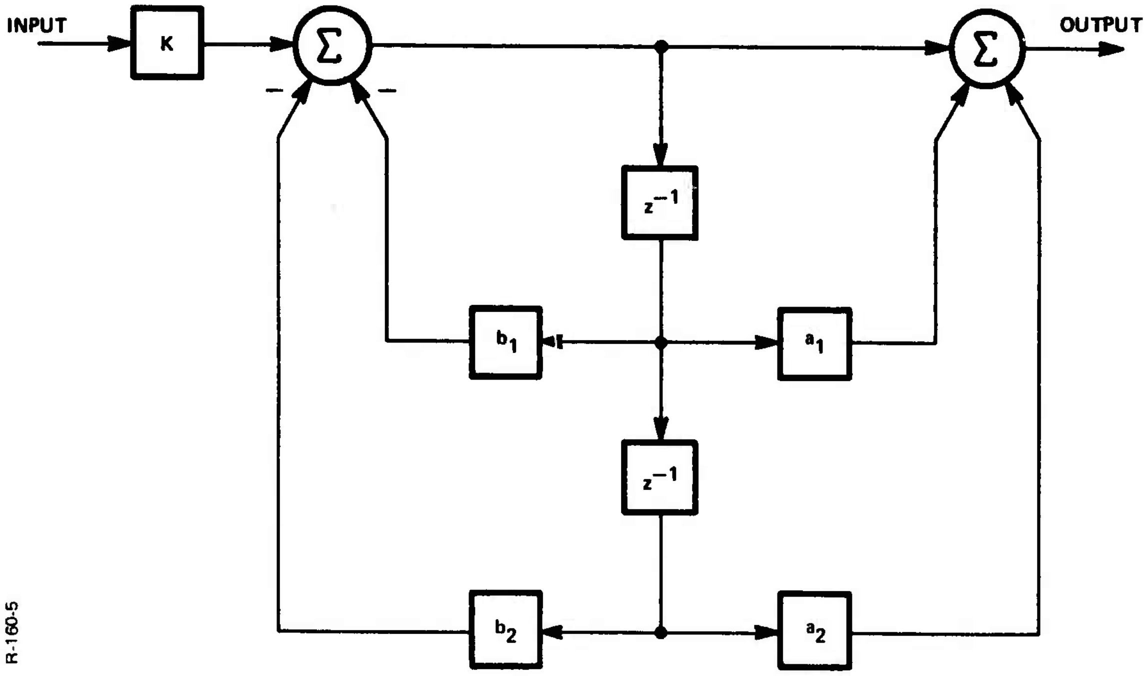


Figure A-2 - Second-Order Recursive Filter Element

The recursive type digital filter is more limited in flexibility than the transversal filter, but is easier to implement in real-time hardware. For the recursive filter, a simple filter element is used repetitively to achieve complex filtering. Usually the simple element consists of a second-order filter section. For each successive input sample, x_i, the output of the filter section is fed back to the input several times. On each feedback cycle, the parameters of the simple filter section are changed, and the total effect is to implement a filter with many cascaded second-order sections. By changing the poles and zeros on each feedback cycle, a wide variety of filter types such as Butterworth, Chebychev, Bessel, etc. can be implemented.

A typical second-order digital filter section is shown in Figure A-2. The z transform transfer function is

$$T(z) = K \frac{1 + a_1 z^{-1} + a_2 z^{-2}}{1 + b_1 z^{-1} + b_2 z^{-2}}$$

Each filter section can contribute two poles and two zeros to the overall filter transfer function. The filter constants a_1, a_2, b_1, b_2, and K determine the gain, poles, and zeros of the filter section. These constants are generally changed for each iteration of the filter element by loading digital values from some external memory. The simple second-order filter element requires only five multipliers and two delay elements. Additional external devices are, of course, required for feeding data back to the input, data buffering, and changing the filter constants.

With appropriate multiplexing and buffering hardware, the single filter section can be time-shared to provide multiple channels of digital filtering. Both multiple channel operation and recursive operation of the filter reduce the speed at which the filter system can sample data from any single channel. Going from 2-pole operation to 4-pole operation halves the sampling rate. Two-channel operation also halves the sampling rate. Operation of the filter system as two channels of 4-pole filters reduces the sampling rate by one fourth, etc.

If a digital filter is to be used within an analog system, analog-to-digital (A/D) conversion must be performed at the input of the filter, and digital-to-analog (D/A) conversion must be performed at the output. In addition, A/D conversion must be preceded by anti-aliasing analog filters. This prevents unwanted high frequency inputs from causing ambiguous digital sample values or aliases. These analog filters must have a cut-off frequency of at most one half the sampling frequency of the digital system and preferably at about one fifth of the sampling frequency. Output filtering is desirable to interpolate the digital output data and reduce D/A converter switching transients.

A typical digital filtering system for analog signals might therefore have the form shown in Figure A-3. If this is a two-channel, 4-pole filter, and the anti-aliasing filters cut-off at one fifth of the sampling frequency, the digital filter would have to process data words at a rate of 20 times the

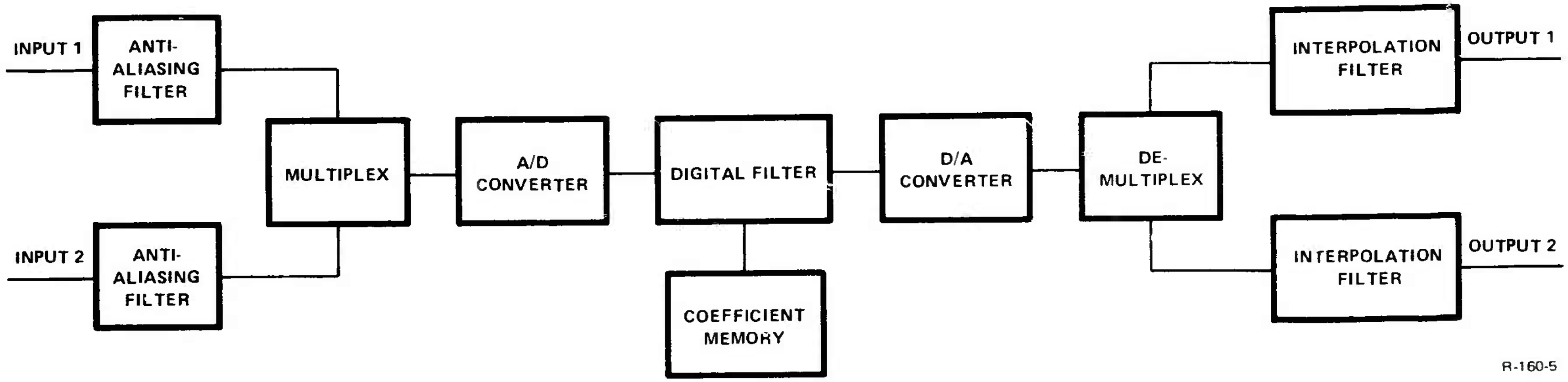


Figure A-3 - Digital Filter System

maximum input frequency. In the AS-11B-1 system, the maximum frequency of interest is about 500 kHz. This requires a processing rate of 10 million data words per second. A typical digital filter processes data words in serial form to simplify multiplication hardware. For a typical word size of 16 bits, the bit rate of the processor would be 160 megabits per second. By using separate digital filters for each channel and using only 2-pole filter implementation, this can be reduced to 40 megabits per second, but this is still a very high bit rate. To attain different filter parameters on every second processing iteration, coefficients must be applied at a rate of 5 million per second. Since the filter coefficients for both channels would be identical, it would not be necessary to change them on every iteration. To tune the filters from the AS-11B-1 computer, the coefficients must be altered periodically (50 times per second) from the computer. The coefficients must, therefore, be stored in buffers or fast random access memory.

From the above discussion, the complexity and speed requirements of a digital filter for processing AS-11B-1 video are seen to be tremendous compared with the analog filter implementation. Commercially available digital filters generally process only signals in the audio or sub-audio frequency range. The advantages offered by digital filters are not important is the AS-11B-1 system. These advantages include:

(1) Stability of operating characteristics

(2) Arbitrary accuracy (at a cost of increased word length for greater accuracy)

(3) Multiplexing capability

(4) Very low frequency capability

(5) Stable high Q implementations

Except for item (1), none of these characteristics are particularly useful in the AS-11B-1 system. Regarding stability, quite adequate stability can be obtained with simpler analog filters. Digital filtering is therefore not considered to be a reasonable approach to implementation of tunable video filtering on the AS-11B-1.

APPENDIX B

STRATEGY MODIFICATIONS

During experimental evaluation of the tunable video filter, certain modifications were made to the basic frequency control strategy functions to determine effects of various strategies on system performance. Program change tapes for these modifications are available for possible future use. The change tapes must be read into the computer after the basic frequency control program tape has been read.

Strategy modifications available are shown in Figures B-1 and B-2. The strategies shown in Figure B-1 modify the low-end filter frequency. The strategy shown in Figure B-2 modifies the high-end filter frequency. After the basic frequency control program tape has been read, successive strategy modification tapes may be read in any order. To return to the basic high-end and low-end frequency control strategies after having read strategy modification tapes, simply reread the basic frequency control program tape.

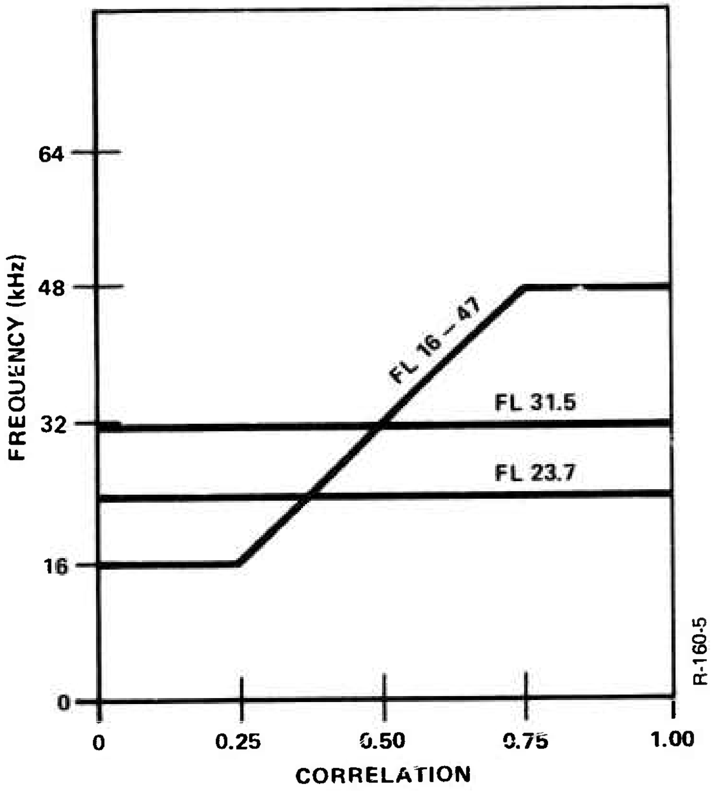


Figure B-1 - Modified Low Frequency Control Strategies

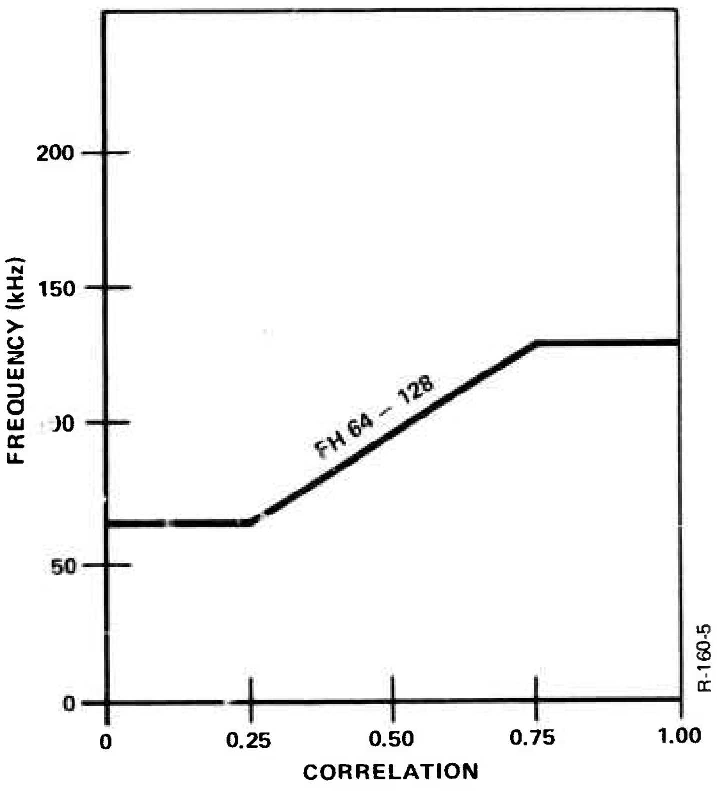


Figure B-2 - Modified High Frequency Control Strategy

MISSION
of
Rome Air Development Center

RADC is the principal AFSC organization charged with planning and executing the USAF exploratory and advanced development programs for information sciences, intelligence, command, control and communications technology, products and services oriented to the needs of the USAF. Primary RADC mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, and electronic reliability, maintainability and compatibility. RADC has mission responsibility as assigned by AFSC for demonstration and acquisition of selected subsystems and systems in the intelligence, mapping, charting, command, control and communications areas.