13:22:06 OCA PAD INITIATION - PROJECT HEADER INFORMATION 02/24/89

Active

Project #: E-21-T11 Cost share #: E-21-314 Rev #: 0
Center # : R6583-T11 Center shr #: F6583-T11 OCA file #: 128
Work type : RES
Contract#: F30602-88-D-0025-0011 Mod #: Document : TO
Prime #: Contract entity: GTRC

Subprojects ? : N
Main project #:

Project unit: EE Unit code: 02.010.118
Project director(s):
PARIS D T EE (404)894-2902

Sponsor/division names: AIR FORCE / GRIFFISS AFB, NY
Sponsor/division codes: 104 / 023

Award period: 890120 to 891231 (performance) 900130 (reports)

Sponsor amount	New this change	Total to date
Contract value	94,568.00	94,568.00
Funded	75,000.00	75,000.00
Cost sharing amount		8,335.00

Does subcontracting plan apply ?: Y

Title: HIGH SPEED PROCESSING CONCEPTS

PROJECT ADMINISTRATION DATA

OCA contact: Brian J. Lindberg 894-4820

Sponsor technical contact

JOHN J. PATTI

DEPARTMENT OF THE AIR FORCE
ROME AIR DEVELOPMENT CENTER/DCCD

Sponsor issuing office

GERARD J. BROWN/PKRM
(315)330-7060
ROME AIR DEVELOPMENT CENTER
DIRECTORATE OF CONTRACTING (PKRM)
GRIFFISS AFB, NY 13441-5700

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): Y
Defense priority rating : DO-A7 GOVT supplemental sheet
Equipment title vests with: Sponsor GIT
NONE PROPOSED OR ANTICIPATED.

Administrative comments -
DELIVERY ORDER PARTIALLY FUNDS TASK C-8-2400 (SUNY) THROUGH 9/30/89.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 04/30/90

Project No. E-21-T11 Center No. R6583-T11

Project Director JOY E B School/Lab EE

Sponsor AIR FORCE/GRIFFISS AFB, NY

Contract/Grant No. F30602-88-D-0025-0011 Contract Entity GTRC

Prime Contract No.

Title HIGH SPEED PROCESSING CONCEPTS

Effective Completion Date 891231 (Performance) 900130 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	Y	
Classified Material Certificate	N	
Release and Assignment	Y	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
[redacted]	Y
GTRC	Y
Project File	Y
Other	N
	N

NOTE: Final Patent Questionnaire sent to PDPI.

EXPERT SCIENCE AND ENGINEERING PROGRAM
CONTRACT NO. F30602-88-D-0025

R&D STATUS REPORT

ERIOD COVERED: January 30, 1989 - June 9, 1989.

ASK NUMBER: C-8-2400 TITLE: HIGH SPEED SIGNAL PROCESSING CONCEPTS

RINCIPAL INVESTIGATOR: Professor Adly T. Fam

NSTITUTION: Dept. of ECE, SUNY/AB, Buffalo, NY 14260

THER PARTICIPANTS AND TITLES:

himin Tsai, Research Assistant
William Klavoon, Research Assistant
Hongsing Lee, Research Assistant
Jon Tucker, Research Assistant
Wernhuar Tarng, Research Assistant
Tapio Saramaki, Research Professor

A. TECHNICAL PROGRESS ACHIEVED ON EFFORT:

1- In the area of FIR filters, the application of optimal partitioning and redundancy removal to filters with coefficients in {1,0} is being examined for VLSI implementation.

2- A new class of digital filter structures that include linear phase FIR filters with at the most 4 times the number of multiplies and adds of a corresponding IIR filter is investigated. An approach based on data reversal is identified, which solves a problem with roundoff noise at the cost of some additional delay.

3- In computations based on residue arithmetic. It is shown that the maximum system dynamic range is attained when the moduli are primes raised to the largest admissible power. Inclusion of error correction in computing the dynamic range is examined.

4- Multi-decoder PLA implementation of a restricted class of logic functions is being investigated for possible applications such as in interconnection networks, and pattern recognition.

5- An interesting approach for implementing an FIR filter of length N, and with arbitrary coefficients, but which requires a much reduced number of delay line taps is identified. This could be of significance in hybrid technology implementations, special device implementations, as well as in adapting any vector-matrix algorithm to FIR filter implementation with reduced communication.

6- A fault tolerance technique for systolic arrays and hierarchical architectures based in optimal multi-level allocation of redundancy is shown to be superior to the well-studied one-level approach, and could have other significant applications.

3. TRAVEL

May 7-11, 1989, The 1989 IEEE International Symposium on Circuits and Systems. Portland, Oregon. To attend conference and present paper listed next.

C. PRESENTATIONS AND PUBLICATIONS

A. Fam, "The Volume of the Coefficient Space Stability Domain of Monic Polynomials," 1989 ISCAS, Portland, Oregon, pp. 1780-1783, May 8-11, 1989.

D. LEVEL OF EFFORT BY EACH CONTRIBUTOR (man-months or man-hours)

Adly T. Fam, 282 man-hours, including cost-sharing
Chimin Tsai, 100 man-hours
William Klavoon, 100 man-hours
Hongsing Lee, 100 man-hours
Jon Tucker, 100 man-hours
Wernhuar Tarng, 50 man-hours
Tapio Saramaki, 160 man-hours

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: JUL-SEP '89

CURRENT QUARTER FUNDING			$476,000.00
DO # 0017	$10,000		
0026	$15,000		
0027	$20,000		
0028	$50,000		
0029	$40,000		
0030	$30,000		
0031	$20,000		
0032	$66,000		
0033	$70,000		
0034	$85,000		
0035	$70,000		
	$476,000		
CURRENT QUARTER EXPENDITURES			$415,422.69
CONTRACT CEILING			$4,200,000.00
FUNDING TO DATE		-	$2,029,675.00
* PENDING COMMITMENTS		-	$253,994.00
AVAILABLE FUNDING			$1,916,331.00
FUNDING TO DATE			$2,029,675.00
YTD EXPENDITURES		-	$849,451.48
OUTSTANDING EXPENDITURES			$1,180,223.52

* DO # 0007	INCREMENTAL FUNDING		$20,000.00
0011	INCREMENTAL FUNDING		$19,568.00
0012	INCREMENTAL FUNDING		$24,700.00
0015	INCREMENTAL FUNDING		$29,783.00
0016	INCREMENTAL FUNDING		$31,250.00
0018	INCREMENTAL FUNDING		$12,000.00
0019	INCREMENTAL FUNDING		$12,000.00
0022	INCREMENTAL FUNDING		$54,693.00
N-0-5703	UNIV OF SOUTHERN FLA/WILSON		$50,000.00
	TOTAL PENDING		$253,994.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: APR-JUN '89

CURRENT QUARTER FUNDING			$160,350.00
DO # 0021	$25,000		
0022	$45,000		
0023	$20,350		
0024	$50,000		
0025	$20,000		
	$160,350		
CURRENT QUARTER EXPENDITURES			$318,963.82
CONTRACT CEILING			$4,200,000.00
FUNDING TO DATE		-	$1,553,675.00
* PENDING COMMITMENTS		-	$718,994.00
AVAILABLE FUNDING			$1,927,331.00
FUNDING TO DATE			$1,553,675.00
YTD EXPENDITURES		-	$434,028.79
OUTSTANDING EXPENDITURES			$1,119,646.21

* DO # 0007	INCREMENTAL FUNDING		$20,000.00
0011	INCREMENTAL FUNDING		$19,568.00
0012	INCREMENTAL FUNDING		$24,700.00
0015	INCREMENTAL FUNDING		$29,783.00
0016	INCREMENTAL FUNDING		$31,250.00
0017	INCREMENTAL FUNDING		$10,000.00
0018	INCREMENTAL FUNDING		$12,000.00
0019	INCREMENTAL FUNDING		$12,000.00
0022	INCREMENTAL FUNDING		$54,693.00
B-9-3621	SRI/LUNT		$20,000.00
N-9-5308	KAMAN SCIENCES		$100,000.00
E-9-7119	DARTMOUTH COLLEGE/CRANE		$100,000.00
N-9-5740	CHRISTIANSON		$15,000.00
N-9-5317	UNIV OF CO/NORGARD		$50,000.00
S-9-7625	UNIV OF CA/DAVIS/KOWELL		$20,000.00
N-9-5314	KAMAN SCIENCES		$100,000.00
N-9-5315	KAMAN SCIENCES		$100,000.00
TOTAL PENDING			$718,994.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: JAN-MAR '89

CURRENT QUARTER FUNDING			$574,457.00
DO # 0001	$90,729		
0011	$75,000		
0012	$75,000		
0013	$59,989		
0014	$49,989		
0015	$70,000		
0016	$43,750		
0017	$30,000		
0018	$22,000		
0019	$38,000		
0020	$20,000		
	$574,457		
CURRENT QUARTER EXPENDITURES			$86,324.15
CONTRACT CEILING			$4,200,000.00
FUNDING TO DATE		-	$1,393,325.00
* PENDING COMMITMENTS		-	$594,651.00
AVAILABLE FUNDING			$2,212,024.00
FUNDING TO DATE			$1,393,325.00
YTD EXPENDITURES		-	$115,064.97
OUTSTANDING EXPENDITURES			$1,278,260.03

* DO # 0007	INCREMENTAL FUNDING		$20,000.00
0011	INCREMENTAL FUNDING		$19,568.00
0012	INCREMENTAL FUNDING		$24,700.00
0015	INCREMENTAL FUNDING		$29,783.00
0016	INCREMENTAL FUNDING		$31,250.00
0017	INCREMENTAL FUNDING		$10,000.00
0018	INCREMENTAL FUNDING		$12,000.00
0019	INCREMENTAL FUNDING		$12,000.00
C-8-2404	STANFORD UNIV/WIDROW		$100,000.00
N-9-5732	GRIFFIN		$25,000.00
A-9-1476	BOWDOIN COLLEGE/CHONACKY		$20,350.00
E-9-7110	UNIV OF LOWELL/SALES		$50,000.00
S-9-7559	UNIV OF MICHIGAN/ROBINSON		$20,000.00
B-9-3621	SRI/LUNT		$20,000.00
N-9-5308	KAMAN SCIENCES		$100,000.00
E-9-7119	DARTMOUTH COLLEGE/CRANE		$100,000.00
	TOTAL PENDING		$594,651.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: OCT-DEC '88

	CURRENT QUARTER FUNDING		$120,834.00
	DO # 0004	$66,680	
	0006	$54,154	
		$120,834	
	CURRENT QUARTER EXPENDITURES		$28,740.82
	CONTRACT CEILING		$4,200,000.00
	FUNDING TO DATE	-	$818,868.00
*	PENDING COMMITMENTS	-	$784,729.00
	AVAILABLE FUNDING		$2,596,403.00
	FUNDING TO DATE		$818,868.00
	YTD EXPENDITURES	-	$28,740.82
	OUTSTANDING EXPENDITURES		$790,127.18

*	DO # 0001	INCREMENTAL FUNDING	$90,729.00
	0007	INCREMENTAL FUNDING	$20,000.00
	C-8-2400	STATE UNIV OF NY/FAM	$95,000.00
	C-8-2402	RENSSELAER/SAULNER	$100,000.00
	B-9-3592	UNIV OF CA/DAVIS/LEVITT	$60,000.00
	N-9-5514	SOHAR INC./HECHT	$50,000.00
	C-9-2015	NCS/O'NEAL	$100,000.00
	A-9-1120	HITEC, INC./KAZAKOS	$75,000.00
	E-9-7057	UNIV OF TX/ARLINGTON/FUNG	$40,000.00
	E-9-7093	MONTANA STATE/JOHNSON	$34,000.00
	S-9-7552	ALFRED UNIV/SYNDER	$20,000.00
	C-9-2404	STANFORD UNIV/WIDROW	$100,000.00
		TOTAL PENDING	$784,729.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: JUL-SEPT '88

CURRENT QUARTER FUNDING			$698,034.00
DO # 0001	$56,000		
0002	$95,141		
0003	$78,854		
0004	$230,000		
0005	$45,561		
0006	$25,000		
0007	$20,000		
0008	$98,374		
0009	$29,403		
0010	$19,701		
	$698,034		
CURRENT QUARTER EXPENDITURES			$0.00
CONTRACT CEILING			$4,200,000.00
FUNDING TO DATE		-	$698,034.00
* PENDING COMMITMENTS		-	$426,563.00
AVAILABLE FUNDING			$3,075,403.00
FUNDING TO DATE			$698,034.00
YTD EXPENDITURES		-	$0.00
OUTSTANDING EXPENDITURES			$698,034.00

* DO # 0001	INCREMENTAL FUNDING		$90,729.00
0002	INCREMENTAL FUNDING		$66,680.00
0003	INCREMENTAL FUNDING		$54,154.00
0004	INCREMENTAL FUNDING		$20,000.00
C-8-2400	STATE UNIV OF NY/FAM		$95,000.00
C-8-2402	RENSSELAER/SAULNER		$100,000.00
TOTAL PENDING			$426,563.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: MAY-JUN '88

	CURRENT QUARTER FUNDING		$0.00
	CURRENT QUARTER EXPENDITURES		$0.00
	CONTRACT CEILING		$4,200,000.00
	FUNDING TO DATE	-	$0.00
*	PENDING COMMITMENTS	-	$766,000.00
	AVAILABLE FUNDING		$3,434,000.00
	FUNDING TO DATE		$0.00
	YTD EXPENDITURES	-	$0.00
	OUTSTANDING EXPENDITURES		$0.00

*	C-8-2120	WESTINGHOUSE/BEAUDET	$56,000.00
	C-8-2129	RENSSELAER/DAS	$100,000.00
	E-8-7066	UNIV OF PENN/STEINBERG	$100,000.00
	E-8-7124	BOSTON COLLEGE/McFADDEN	$35,000.00
	E-8-7125	BRANDEIS UNIV/HENCHMAN	$23,000.00
	E-8-7126	PENN STATE/CASTLEMAN	$22,000.00
	A-8-1631	UNIV OF PENN/STEINBERG	$100,000.00
	B-8-3617	GA WASHINGTON UNIV/MELTZER	$100,000.00
	B-8-3618	GA WASHINGTON UNIV/BERKOVICH	$100,000.00
	C-8-2492	GA TECH/SMITH	$50,000.00
	A-8-1203	GA TECH/HUGHES	$80,000.00
		TOTAL PENDING	$766,000.00

E-2-1-11

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: OCT-DEC '89

CURRENT QUARTER FUNDING				$292,994.00
DO #	0001	$9,000	C-8-2129	
	0011	$19,568	C-8-2400	
	0012	$24,700	C-8-2402	
	0015	$29,783	C-9-2015	
	0016	$31,250	A-9-1120	
	0018	$12,000	E-9-7093	
	0019	$62,000	C-9-2109	
	0022	$54,693	C-9-2404	
	0028	$50,000	N-9-5308	
		$292,994		

CURRENT QUARTER EXPENDITURES		$286,691.16
CONTRACT CEILING		$4,200,000.00
FUNDING TO DATE	-	$2,322,669.00
* PENDING COMMITMENTS	-	$595,000.00
AVAILABLE FUNDING		$1,282,331.00
FUNDING TO DATE		$2,322,669.00
YTD EXPENDITURES	-	$1,136,142.64
OUTSTANDING EXPENDITURES		$1,186,526.36

*	DO # 0007	S-8-7592	INCREMENTAL FUNDING	$20,000.00
	0029	E-9-7119	INCREMENTAL FUNDING	$60,000.00
	0030	N-9-5317	INCREMENTAL FUNDING	$20,000.00
	0034	N-9-5314	INCREMENTAL FUNDING	$15,000.00
	0016	N-9-5315	INCREMENTAL FUNDING	$30,000.00
	N-0-5703	UNIV OF SOUTHERN FLA/WILSON		$50,000.00
	A-0-1102	UNIV OF CA/SMOOT, BARBER, GT		$100,000.00
	P-0-6011	NCSU/VANDERLUGT		$100,000.00
	C-0-2456	NEW JERSEY INST/BAR-NESS		$100,000.00
	P-0-6014	STEVENS INST/ZMUDA		$100,000.00
	TOTAL PENDING			$595,000.00

WAITING FOR PROPOSALS:
P-0-6018 UAH/CAULFIELD
P-0-6021 GT/SUMNERS
P-0-6022 CORNELL UNIV/TANG
B-0-3353 ROCHESTER INST/LASKY

E-21-T11

ROME AIR DEVELOPMENT CENTER
EXPERT SCIENCE AND ENGINEERING PROGRAM
CONTRACT NO. F30602-88-D-0025

R&D STATUS REPORT

PERIOD COVERED: June 10, 1989 - September 30, 1989.

TASK NUMBER: C-8-2400 TITLE: HIGH SPEED SIGNAL PROCESSING CONCEPTS

PRINCIPAL INVESTIGATOR: Professor Adly T. Fam

INSTITUTION: Dept. of ECE, SUNY/AB, Buffalo, NY 14260

OTHER PARTICIPANTS AND TITLES:

Chimin Tsai, Research Assistant
William Klavoon, Research Assistant
Hongsing Lee, Research Assistant
Jon Tucker, Research Assistant
Wernhuar Tarng, Research Assistant
Gustavo Belforte, Visiting Profesoor
Yong Hoon Lee, Assistance Professor

A. TECHNICAL PROGRESS ACHIEVED ON EFFORT:

1- Selection Filters and Commutativity with Memoryless Nonlinearities: The class of dynamical discrete-time systems which commute with memoryless monotone nonlinearities is characterized, and is found to belong to the class of selection filters, in which the output is selected according to some rule from the input window. Properties of this class are examined, and a paper is submitted (see section C).

2- A new class of digital filter structures that include linear phase FIR filters with at the most 4 times the number of multiplies and adds of a corresponding IIR filter is investigated. An approach based on data reversal is identified, which solves a problem with roundoff noise at the cost of some additional delay. Two papers are submitted, one entitled, "Efficient Linear Phase Filters Based on Switching and Time Reversal," and the second "FIR Filters Based on Switching and Resetting of IIR Filters." (see section C).

4- A fault tolerance technique for systolic arrays and hierarchical architectures based in optimal multi-level allocation of redundancy is shown to be superior to the well-studied one-level approach. A paper entitled "Hierarchical Approach for the Design of Two-dimensional Fault-tolerant Systolic Arrays" is to be submitted. (see section C)

5- Generating Edges of D-Stable Polynomials: A nice extension of a theorem by Lucas is presented. Two new theorems that could be of value in the areas of control, communications, and signal processing are presenred in an invited paper (section C).

6- FIR filters with coefficients in {1,0}: VLSI implementation. In progress.

7- Residue Arithmetic: Dynamic range and fault tolerence considerations. In progress.

B. TRAVEL

June 28-29, 1989. Visit to RADC by A. Fam

C. PRESENTATIONS AND PUBLICATIONS

Adly T. Fam and Yong H. Lee, "Selection Filters and Commutativity with Memoryless Nonlinearities," submitted for presentation at the 1990 ISCAS, New Orleans, Louisiana, May 1-3, 1990.

Chimih Tsai and Adly Fam, "Efficient Linear Phase Filters Based on Switching and Time Reversal," submitted for presentation at the 1990 ISCAS, New Orleans, Louisiana, May 1-3, 1990.

Tapio Saramaki and Adly Fam, "FIR Filters Based on Switching and Resetting of IIR Filters," submitted for presentation at the 1990 ISCAS, New Orleans, Louisiana, May 1-3, 1990.

Tein-Hsiang Lin and Adly T. Fam, "A Hierarchical Approach for the Design of Two-dimensional Fault-Tolerant Systolic Arrays," to be submitted for publication.

A. Fam, "Generating Edges of D-Stable Polynomials," invited for presentation at the 28th IEEE CDC, Tampa, Florida, December 13-15, 1989.

D. LEVEL OF EFFORT BY EACH CONTRIBUTOR (man-months or man-hours)

Adly T. Fam, 480 summer, 50 academic year man-hours, including cost-sharing
Chimin Tsai, 480 summer, 110 academic year man-hours
William Klavoon, 480 summer, 110 academic year man-hours
Hongsing Lee, 215 man-hours
Jon Tucker, 200 man-hours
Wernhuar Tarng, 240 man-hours
Gustavo Belforte, 80 man-hours
Yong Hoon Lee, 160 man-hours

High Speed Signal Processing Concepts

Task Assignment No. C-8-2400, under Prime Contract No. F30602-88-D-0025
Subcontract No. E-21-T11-S1
For the Period of January 30, 1989 to December 31,1989

Final Report
March 15, 1990

Prepared by

Adly T. Fam
Department of Electrical and Computer Engineering
State University of New York at Buffalo
Buffalo, NY 14260
Tel. (716)636-2423, 2422
E-mail afam@sunfam.eng.buffalo.edu
or elefam@ubvms.bitnet

High Speed Signal Processing Concepts

1.0 Abstract

This effort is characterized by introducing novel concepts and algorithms for high throughput, arithmetic intensive applications in signal processing and communications. In addition, efficient implementations of these algorithms in a variety of modalities, including VLSI, and consideration of reliability and fault-tolerance issues are included. In the sequel, the main achievement in each topic is summarized, and cited publications and presentations which resulted from this effort attached.

The highlights of the achievements of this effort and their implications are:

1. Linear phase FIR filters with computational efficiency of IIR filters. This is a breakthrough that removes a fundamental impediment in using linear phase FIR filters in application with sharp transition bands, where very long filters result, as in designing multiband filters in communications applications.
2. VLSI implementation of FIR filters with binary coefficients based on optimal partitioning and redundancy removal which preserves the *O(N/log N)* performance based on the number of additions per output in the more involved VLSI environment with interconnections and area-time product taken into account.
3. Optimal distribution of redundancy in hierarchical architectures, with faulty interconnects taken into consideration. This work on fault-tolerance applies also to yield improvement in VLSI and WSI. It is also applicable to real-time fault-tolerance combined with testability, but such extensions require further research for specific applications.
4. The class of all discrete-time systems which commute with every monotone increasing nonlinearity is completely characterized. This class is found to be of the selection filter type, in which each output is selected from the input window according to some decision criteria. Clearly this could be of impact in communications applications, as further investigation could indicate. Also, an efficient implementation of one-dimensional recursive median filters is discussed.
5. Prime power moduli are found to optimize the dynamic range of RNS-based computation and signal processing. Identical modules that are firmware programmable are a possible basis for such a system, and could be produced for a wide range of applications. Further research is required to continue the preliminary investigation of the arithmetic for prime power moduli of this effort.
6. The volume of the coefficient space domain of polynomials with roots in a given circle is evaluated. This could be the basis of global sensitivity analysis, resolution of

spectral estimation and identification algorithms by actually counting the number of polynomials with finite wordlength in a given class. This study could also has information theoretic interpretation as the entropy of classes of polynomials in their coefficient space.

7. It is shown that if a polynomial has its roots in a convex domain which contains the origin, then the roots of any linear convex combination of the polynomial and its normalized derivative are in the same convex domain. This result and its generalization could have implications in robustness analysis of systems, and in some signal processing and communications applications connected to the Hilbert transform.

2.0 FIR Filters Based on Switching and Resetting of IIR Filters

Linear phase FIR filters with computational efficiency of IIR filters. This is a breakthrough that removes a fundamental impediment in using linear phase FIR filters in application with sharp transition bands, where very long filters result, as in designing multiband filters in communications applications.

2.1 Properties and Structure of Linear Phase FIR Filters Based on Switching and Resetting of IIR Filters

New recursive structures are introduced for implementing long linear phase FIR filters using a very small number of multipliers. The implementation of these filters uses the principle of switching and resetting between two identical copies of the same IIR filter, introduced in Ref.1. The impulse response of these filters is a truncated and shifted version of the response of a filter $G(z)G(z^{-1})$ where $G(z)$ is a stable IIR filter and $G(z^{-1})$ is the corresponding unstable one. The filters are implemented as a parallel combination of several branches, each generating a truncated response corresponding to a complex conjugate pole pair and its reciprocal pair. The truncation is performed using a feedforward term, which provides a pole-zero cancellation. To stabilize the pole-zero cancellation and to avoid the quantization error from growing excessively, the branch filters are then implemented by applying the principle of switching and resetting. It is shown, via an example in Pub.1, that using the above approach we can design a nearly optimum FIR filter of order larger than *500* using just *17* adjustable parameters.

2.2 Efficient Linear Phase Filters Based on Switching and Time Reversal

Although implementation of $G(z^{-1})$ via switching and resetting stabilizes pole-zero cancellation, coefficient sensitivity and roundoff noise requires extra bits. To avoid these effects, reversal of the data blocks before and after filtering, combined with replacing $G(z^{-1})$ by $G(z)$ results in an implementation of $G(z^{-1})$ using a stable filter. As shown in Pub.2, this results however in increased group delay compared to the above approach.

3.0 VLSI FIR Filters Based on Optimal Reduction

VLSI implementation of FIR filters with binary coefficients based on optimal partitioning and redundancy removal which preserves the *O(N/log N)* performance based on the number of additions per output in the more involved VLSI environment with interconnections and area-time product taken into account.

In Ref.2 an efficient realization of FIR filters based on space-time duality is presented. In this approach, all the fixed-point multiplications are reduced to additions, and then a new type of redundancy is identified and removed to reduce the number of equivalent additions per output. To avoid the relative cost of multiplications and additions in fixed-point arithmetic, which is highly implementation dependent, this approach is applied to FIR filters with coefficients in *{0,1}* in Ref.3. With addition as the only arithmetic operations involved, the effectiveness of the approach was made clear in Ref.3, where in comparison to up to *N-1* additions per output, only *O(N/log N)* are required. However, in a VLSI implementation, the additions per output is not an adequately representative cost function. The cost of interconnections, memory, area-time trade-offs, and other house keeping functions should also be incorporated. As indicated in Ref.3, a highly parallel VLSI implementation results in poor performance for the new algorithm with only a small advantage over the regular direct design. In Pres.2 it is shown that a carefully defined highly sequential design results in an area-time product which preserves most of the performance of the algorithm. Bill Klavoon is continuing with this effort, examining the details of actual VLSI designs of parts of which an FIR filter, filter bank, with single or multibit coefficients are composed. This effort is a prime candidate for continuation beyond the current funding if the encouraging results obtained are to be developed into actual chip or chip set layouts. Also, VLSI implementation of the most general form of the optimal partitioning and redundancy removal applied to partial sums in Ref.4 is another candidate for further research. This would result in a chip or chip set layout for vector matrix multiplication, and applications that could be mapped into the form of vector matrix multiplication.

4.0 A Hierarchical Approach for the Design of Two-Dimensional Fault-Tolerant Systolic Arrays

Optimal distribution of redundancy in hierarchical architectures, with faulty interconnects taken into consideration. This work on fault-tolerance applies also to yield improvement in VLSI and WSI. It is also applicable to real-time fault-tolerance combined with testability, but such extensions require further research for specific applications.

The reliability evaluation of fault-tolerant systolic arrays is often considered in the current literature with the assumption of no faulty interconnections. This leads to incorrect conclusions about the effect of increasing the redundancy. It would then appear that more redundancy results in higher reliability. In Pub.3, a reliability model for fault-tolerant systolic arrays that incorporates the effect of faulty processing units, as well as faulty switches and interconnections is developed and applied in evaluating different redundancy schemes. In particular, a simple local redundancy scheme is compared with a two-level

redundancy one which introduces redundancy hierarchically in two levels. It is found that for high redundancy, the two-level scheme can achieve much higher reliability than the local one, given an identical number of spare units. However, for low redundancy, the local scheme is less costly to implement, yet performs slightly better than the two-level one as shown in Pub.3.

5.0 Selection Filters

The class of all discrete-time systems which commute with every monotone increasing nonlinearity is completely characterized. This class is found to be of the selection filter type, in which each output is selected from the input window according to some decision criteria. Clearly this could be of impact in communications applications, as further investigation could indicate. Also, an efficient implementation of one-dimensional recursive median filters is discussed.

5.1 Selection Filters and Commutativity with Memoryless Nonlinearities

The class of nonrecursive filters that commute with every monotone increasing, zero-memory nonlinearity (ZNL) is characterized in Pub.4. Specifically, it is shown that a nonrecursive filter commutes with every monotone increasing ZNL if and only if it is a rank-based selection (RBS) filter that replaces each input value with one of its neighboring input data which is selected depending on the relative amplitudes of the data. It is also shown that RBS filters commuting with every nondecreasing ZNL are stack filters that can be represented as finite maximum-minimum operations.

5.2 Efficient Implementation of One-Dimensional Recursive Median Filters

It is shown in Pub.5 that one-dimensional (1-D) recursive median (RM) filtering, the present output is fully determined by the input data in the window and by the most recent output. All other past outputs are shown to be redundant. Based on this result, efficient algorithms and VLSI implementation for 1-D RM filters are presented, and shown to compare favorably with those of standard median filtering.

6.0 Residue Number Systems with Prime Power Moduli

In computation based on residue arithmetic via identical modules which admit firmware programmability, it is shown in Pres.4 that the maximum system dynamic range is attained when the moduli of the individual modules are prime powers. Evaluating the required number of modules and their wordlength, to implement a required overall dynamic range is presented Discussion of primitive roots, and ways to implement arithmetic in prime power system is also presented, but requires further research.

7.0 Coefficient Space Properties of Polynomials

The volume of the coefficient space domain of polynomials with roots in a given circle is evaluated. This could be the basis of global sensitivity analysis, resolution of spectral estimation and identification algorithms by actually counting the number of polynomials with finite wordlength in a given class. This study could also has information theoretic interpretation as the entropy of classes of polynomials in their coefficient space.

Also, It is shown that if a polynomial has its roots in a convex domain which contains the origin, then the roots of any linear convex combination of the polynomial and its normalized derivative are in the same convex domain. This result and its generalization could have implications in robustness analysis of systems, and in some signal processing and communications applications connected to the Hilbert transform.

7.1 The Volume of the Coefficient Space Stability Domain of Monic Polynomials

The volume of the coefficient space domain of polynomials with zeros in the unit circle is evaluated in Pub.6. This volume is an upper bound on that of any domain of coefficient variations of any shape under which stability is invariant. Volumes of related domains are computed and the results extended to polynomials with zeros in a circle of arbitrary radius.

This approach of studying polynomials as a class from a global geometry point of view is particularly interesting in studying the entropy of polynomials in their coefficient space, and in developing global measures of the ability of models with finite wordlength to achieve a given resolution in applications such as spectral estimation, identification, and target recognition.

7.2 Generating Edges of *D*-Stable Polynomials

It is shown in Pub.7 that if a polynomial P of degree n is D-stable, where D is convex and contains the origin, then all convex combinations of P and its normalized derivative, zP'/n, are also D-stable. It is also shown that convex linear combinations of the logarithmic derivatives of D-stable polynomials with a convex D, have both their poles and zeros in D. Both theorems are motivated by a theorem of Lucas, and provide an example of how to generate edges and polytopes of D-stable polynomials and rational functions from a given set of D-stable polynomials. This result and its generalization could have implications in robustness analysis of systems, and in some signal processing and communications applications connected to the Hilbert transform.

8.0 References, Publications, and Presentations

The Following references are cited in this report. This is followed by the publications resulting from this effort, and presentations and discussions that took place in a final report visit to RADC on Feb. 9, 1990.

8.1 References

1.A. T. Fam, "FIR Filters that Approach IIR Filters in their Computational Efficiency," *Twenty-First Asilomar Conference on Signals, Systems, and Computers,* Pacific Grove, California, pp. 28-30, Nov. 2-4, 1987.

2.A. T. Fam, "Space-Time Duality in Digital Filter Structures," *IEEE Trans. Acoust., Speech, Signal Processing*, vol. 31, no. 3, pp. 550-556, June 1983.

3.A. T. Fam, "A Multi-Signal Bus Architecture for FIR Filters with Single Bit Coefficients," *ICASSP-84*, San Diego, pp. 11.11.1-11.11.3, March 19-21, 1984.

4.A. T. Fam, "Optimal Partitioning and Redundancy Removal in Computing Partial Sums," *IEEE Trans. Comput.*, vol. 36, no. 10, pp. 1137-1143, October 1987.

8.2 Publications Resulting from Effort

1.Tapio Saramäki and Adly T. Fam, "Properties and Structure of Linear-Phase FIR Filters Based on Switching and Resetting of IIR Filters," To be presented at *ISCAS'90*, New Orleans, Louisiana, May 1-3, 1990.

2.Chimin Tsai and Adly T. Fam, "Efficient Linear-Phase Filters Based on Switching and Time Reversal," *ISCAS'90*, New Orleans, Louisiana, May 1-3, 1990.

3.Tein-Hsiang Lin and Adly T. Fam, "A Hierarchical Approach for the Design of Two-Dimensional Fault-Tolerant Systolic Arrays," Submitted to the *1990 International Conference on Parallel Processing*, St. Charles, Illinois, Aug. 13-17, 1990.

4.Adly T. Fam and Yong H. Lee, "Selection Filters and Commutativity with Memoryless Nonlinearities," I*SCAS'90*, New Orleans, Louisiana, May 1-3, 1990.

5.Sung-Jea Ko, Yong Hoon Lee, and Adly T. Fam, "Efficient Implementation of One-Dimensional Recursive Median Filters," Submitted to *IEEE Trans. Circuits Syst.*

6.Adly T. Fam, "The Volume of the Coefficient Space Stability Domain of Monic Polynomials," *ISCAS'89*, Portland, Oregon, pp. 1780-1783, May 8-11, 1989.

7.Adly T. Fam, "Generating Edges of *D*-Stable Polynomials," *28th CDC*, Tampa, Florida, pp. 2271-2272, Dec. 13-15, 1989.

8.3 Presentations at RADC

The following presentations and discussions were part of a final report visit to RADC on Friday, Feb. 9, 1990.

1.Tsai, "Efficient Linear Phase Filters Based on Switching and Time Reversal"

2.Klavoon, "VLSI FIR Filter Design Based on Optimal Reduction"

3.Lin, "A Hierarchical Approach for the Design of Two-Dimensional Fault-Tolerant Systolic Arrays"

4.Fam, "RNS with Prime Power Moduli"

5.Fam, Discussion of:

-The Coefficient Space Geometry of Polynomials

-Work on Selection Filters with Yong Lee

-Work on Switching and Resetting with Tapio Saramäki

-Further Research, including extension of above topics and the Fast Chirp Filter and Transform. A white paper in the form of a preliminary proposal entitled "Fast Chirp Filtering and Arithmetic Intensive Signal Processing" submitted to John Patti.

High Speed Signal Processing Concepts

Publications:

1. Tapio Saramäki and Adly T. Fam, "Properties and Structure of Linear-Phase FIR Filters Based on Switching and Resetting of IIR Filters," To be presented at *ISCAS'90*, New Orleans, Louisiana, May 1-3, 1990.
2. Chimin Tsai and Adly T. Fam, "Efficient Linear-Phase Filters Based on Switching and Time Reversal," *ISCAS'90*, New Orleans, Louisiana, May 1-3, 1990.
3. Tein-Hsiang Lin and Adly T. Fam, "A Hierarchical Approach for the Design of Two-Dimensional Fault-Tolerant Systolic Arrays," Submitted to the *1990 International Conference on Parallel Processing*, St. Charles, Illinois, Aug. 13-17, 1990.
4. Adly T. Fam and Yong H. Lee, "Selection Filters and Commutativity with Memoryless Nonlinearities," I*SCAS'90*, New Orleans, Louisiana, May 1-3, 1990.
5. Sung-Jea Ko, Yong Hoon Lee, and Adly T. Fam, "Efficient Implementation of One-Dimensional Recursive Median Filters," Submitted to *IEEE Trans. Circuits Syst.*
6. Adly T. Fam, "The Volume of the Coefficient Space Stability Domain of Monic Polynomials," *ISCAS'89*, Portland, Oregon, pp. 1780-1783, May 8-11, 1989.
7. Adly T. Fam, "Generating Edges of *D*-Stable Polynomials," *28th CDC*, Tampa, Florida, pp. 2271-2272, Dec. 13-15, 1989.

High Speed Signal Processing Concepts

Presentations:

Tsai:

- *Efficient Linear Phase Filters based on Switching and Time Reversal*

Klavoon:

- *VLSI FIR Filter Design Based on Optimal Reduction*

Lin:

- *A Hierarchical Approach for the Design of Two-Dimensional Fault-Tolerant Systolic Arrays*

Fam:

- *RNS with Prime Power Moduli*

-Entropy of Polynomials in their Coefficient Space

-Brief Discussion of work on Selection Filters with Yong Lee and on Switching and Resetting with Tapio Saramaki

-Discussion of Further Research: The Fast Chirp Filter and Transform, above topics ... etc.