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Automatic FIR Filter Design Met od and Tool based on Genetic Algorit ms

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***Abstract*—A FIR Filter design method and its respective tool using genetic algorithms were developed. The main feature of this method is to offer a transparent mode for the user who doesn't know evolutionary computation, as well as its parameters. The user inputs the filter specifications and gets a sub-optimal result in an average number of four attempts. The sub-optimal criterion was based on the Rabiner, Parks and McClellan algorithm and the implemented software was built using the GALOPPS tool.**

***Index Terms*—FIR filter design, genetic algoritms, Galopps, Rabiner Parks and McClellan algorithm, Remez.**

I INTRODUCTION

T e design of FIR (*Finite Impulse Response*) digital filters using tec niques of DSP is an automatic procedure T ere are computer programs like MATLAB and DSPLAY t at offer t is facility Some of t ese tec niques use met ods like window remez and frequency sampling Details about t ese met ods can be found in   ] T e only t ing t e user needs to concern is t e t e FIR filter specification w ic can involve some few additional parameters related to t e met od c osen

FIR filter design using GAs (*genetic algorithms*) as been studied at least for   years   ] But c oosing t is way to get a digital filter t e user usually as to know a considerable number of additional parameters besides t e FIR filter specifications   T ey are t e GA parameters Some of t em need to be adjusted at eac new filter specification Anot er feature of a met od based on GAs is t e stoc astic be avior of t is kind of application: t e user previously needs to know t at it can be necessary to run more t an one execution to get an interesting solution And t is solution can be different at eac time t e application is run T ese two features of a FIR filter design tool based on GAs tend to restrict it for people t at ave some knowledge of evolutionary computation One illustration of a tool like t is is presented in Fig   T e main contributions t is work are two: a) t e user doesn´t need to specify any GA parameter All of t em already fixed in optimal values or are self adjustable; b) and t e quality of t e results on an average number of four attempts are sub optimal Some of t ese results can be used in ard FIR filter specifications in a better condition t an t e specialist met ods A sub optimal pattern was created and t e reference for t is was t e Parks McClellan met od implemented in MATLAB t roug t e remez command   ]

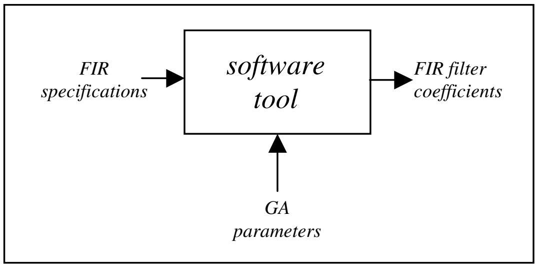

Figure 1: One model of a GA FIR filter design tool

II FIR FILTER DESIGN

Details about t e topics covered by t is section can be found in   ] A FIR digital filter frequency response can be calculated from:

$$H(k)=\sum_{n=}^{M-}h(n)\times e^{\left(\frac{-j\ \ \pi}{N}\right)\times kn} \qquad (\ )$$

In eq ( ): *H(k)* is t e Discrete Fourier Transform complex vector T is is t e FIR digital filter frequency response; *N* is t e number of collected points during t e sampling process; *k* is an index varying from zero to *N-1*; *h(n)* is t e FIR filter response vector to t e unit impulse T is vector corresponds to t e FIR filter coefficients; and *M* is t e number of t e FIR filter coefficients

A digital filter gives a realizable version of a desired frequency response t at was specified as part of t e filter specifications T is appens because an ideal digital filter response is unrealizable

To express *H(k)* as a function of t e normalized frequency it can be used   ]:

$$f = \frac{k}{N - } \qquad ( )$$

In eq ( ) *f* is t e normalized frequency ranging from to cicles sample

Depending on t e number of coefficients and t e simmetry of *h(n)* t e FIR filters can be classified in four categories (types I to IV) t ree of t em requiring some restrictions to give a specific frequency response T is work covers t e four categories

T e complex vector *H(k)* is more useful w en viewed as separated in magnitude and p ase frequency responses T ere is a symmetry in t e FIR filters coefficients t at guarantees a linear p ase frequency response So a FIR filter specification is often expressed only bit its magnitude frequency response One set of FIR filter parameters often used in a specification is presented in Fig

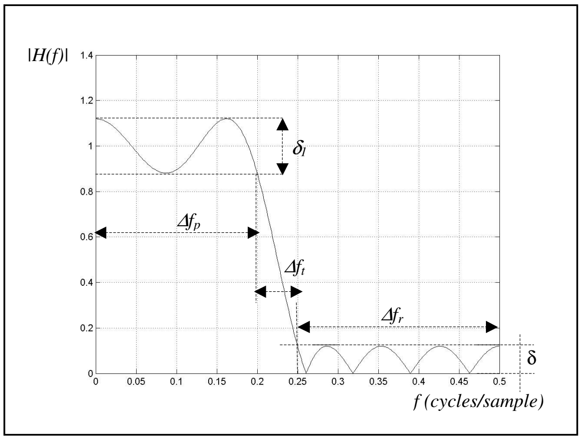

Figure 2: One set of FIR filter parameters

T e description of t ese parameters are: a) δ_1 δ_2: Maximum ripple allowed for bands and respectively; b) Δf_p Δf_r: bandwidt of bands and respectively; c) Δf_t: transition bandwidt between bands

T ere are also ot er specification parameters needed w ic were not presented in Fig T ey are t e amplitude leves of bands and A_1 and A_2 respectively and t e number of FIR filter coefficients *M* In t is work a t ird band was used to provide passband and stopband filters Returning to Fig t ese parameters are t e FIR specifications

FIR filters are Linear and Time Invariant systems So t e filtering process can be made troug t e convolution of t e FIR filter coefficients *h(n)* and t e signal *x(n)* to be filtered:

$$y(n) = x(n) * h(n) = \sum_{k=}^{U} x(k)h(n-k) \qquad ( )$$

In eq ( ): *y(n)* is t e filtered signal; *h(n)* is t e FIR filter unit response; *x(n)* is t e signal to be filtered; * is t e convolution operator symbol; *U* is a number w ic is t e sum of t e number of samples founded in *h(n)* and in *x(n)*; and *n* varies from zero to *U-1*

It is possible to get from eq ( ) t e following conclusion: t e larger number of *h(n)* coefficients (*M*) t e more precise will be t e filtering process Larger values of *M* offer a better quality of filtering Better ere can be understood as a FIR filter frequency response wit a minimum transition widt and a minimum value of ripple But also t roug eq ( ) it is possible to conclude t at for a same signal *x(n)* to be filtered t e number of products between *x(n)* and *h(n)* is regulated by t e number of FIR filter coefficients *M* But larger values of *M* cause larger delays during t e filtering process T is can be unacceptable in some real time applications

One of t e main advantages of t e Parks McClellan met od is t e possibility of previously calculate t e value of *M* t at will satisfy a FIR filter specification w ic will ere be called t e recommended *M* or M_{rec} T is is done t roug empirical formulas Smaller values for δ_1 δ_2 or Δf_t will require a larger value for M_{rec}

T is work also tries to enforce t e following area of study: t e fetc for an acceptable FIR filter response in terms of quality wit a minimum value of FIR filter coefficients

III GENETIC ALGORITHMS AND THE PROPOSED MODELING

Details about t e topics covered in t is section can be found in 4]

A GA is based on a sequence of actions t at among ot ers can be represented by Fig A brief description of t ese actions wit t e model adopted by t is work is:

a) a possible numerical solution of t e problem is codified as an individual Suc representation usually adopts symbols to codify t e numerical solution T e vector of t e individual corresponds to a c romosome In t is work an individual is t e *h(n)* vector represented by t e binary alp abet eit er in Gray or binary positional As a c romosome *h(n)* is yet represented by a bit string of integers T e integer to decimal decodification is made by portions of bits Eac portion gives a precision number ranging from – to w ic is one FIR filter coefficient;

b) a set of individuals is generated at random T is set is called population and corresponds to t e step in Fig It is called t e searc space *S* t at corresponds to all possible solutions t at can be formed wit t e c osen alp abet In t is work t e searc space is variable wit t e number of FIR filter coefficients according to:

$$S = {}^{l} \qquad (4)$$

In eq (4): *S* is t e searc space; and *l* is t e size in bits of t e c romosome *l* depends of *M* and only one alf of t e coefficients must be codified in t e c romosome because of t e FIR filter symmetry proprierty For example for *M=14* only t e first seven coefficients must be codified In t is way *l* = × = So *S* = = 5 × ;

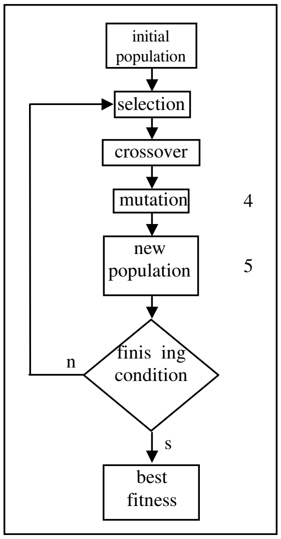

Figure 3: A GA basic flow

c) t is population is submitted to an evaluation Eac individual is tested according to ow good it is as an optimal or sub optimal numerical solution for t e proposed problem In t is way eac individual receives a score T is evaluation is called fitness In t is work t e fitness function c osen is:

$$fitness = \sum_{i=}^{N-} \frac{}{\left(\left|H_d(f_i)\right| - \left|H_i(f_i)\right|\right)} \qquad (5)$$

In eq (5): *fitness* is t e fitness function; $|H_d(f)|$ is t e desired (given by user specification) magnitude frequency response; and $|H_i(f)|$ is t e magnitude frequency response from eac individual $|H_i(f)|$ is calculated t roug Eq ( ) because an individual corresponds to one vector *h(n)* T is fitness function numerically indicates ow close an answer from an individual is from t e desired answer T is appens in step one of Fig in t e first time;

d) it is applied in t is evaluated population some mec anism of selection T is is an attempt to exclude from t e next steps individuals wit low values of fitness In t is work it was used t e following selection processes: Roullete W eel Stoc astic Tournament and t e Stoc astic Universal Sampling T is appens in step two of Fig ;

e) t e next step wit t e selected population is a recombination mec anism called crossover A crossover consists basically of c anges in portions of t e c romosome between two individuals T e crossover is applied in t is selected population wit a probability *pcross* between to In t is work t e following crossover tec niques were used: one point and two point crossover T is appens in step t ree of Fig ;

f) after t is anot er operation in t e c romosomes is applied It is t e mutation t at consists basically of a c ange in one or more bits in an individual at random T is operation is applied wit a probability *pmutation* also ranging from to In t is work t e following mutation operations were used: single bit mutation and multiple field mutation T is is step four in Fig ;

g) t is new population is evaluated as t e same way as made in t e step described in item *c* T is appens in step five of Fig ;

) it is called *generation* t e steps covered by items *d* to *g* inclusive Every time a generation is concluded a finis ing condition is tested to end t e GA execution In t is work t e finis ing condition is a maximum generation number T is is step six in Fig ;

i) if t e finis ing condition is not true t ere is a return to t e step t at corresponds to item *d* and a new generation cycle is executed T is appens in t e decision structure in Fig ;

j) if t e finis ing condition is true t e last population is obtained and t e individual wit t e ig est value of fitness in t is population is t e best solution t e GA can give In t is case it will be t e best *h(n)* founded

Returning to Fig t ese parameters are t e ones automatically set by t e tool called GA parameters

IV FIR FILTER DESIGN WITH GENETIC ALGORITHMS

Counting from] until t ese days more t an one undred FIR Filter Design met ods using GAs are already publis ed e g 5]] and] In t ese works t e prior goal was not t e fetc for a met od or software based on GAs for give FIR filter coefficients wit out t e need to adjust evolutionary parameters at eac new specification and wit a predetermined number of mean trials to get an acceptable answer

Two related works were found T e first is a MATLAB toolbox] Some differences between t at tool and t is work are: a) in t at tool t e GA parameters are configurable t at is t e user must know GAs In t is work t is kind of knowledge is not necessary; b) T e platform: to run t at application it is necessary to ave MATLAB In t is work t e final version of t e tool runs over Windows directly T e second work also a MATLAB toolbox is a tool called CSDFIR] T e final version of t is tool is automatic but today it owned by a private company

V METHODOLOGY

To ac ieve t e proposed goals t e following strategy was taken: a) two sub optimal conditions related to a well know specialist met od were specified; b) and a bank of FIR filter frequency response specifications was specified T ese filter specifications tried to cover all t e possible kinds of ard and easy to solve FIR filters All of t em were specified wit or amplitudes Arbitrary levels were not proposed because t e size of t e filter bank would grow considerably

Wit t e conditions and t e filter bank a t ree p ase group of tests was proposed: a) P ase : t e filter bank was tested wit a fixed number of coefficients from types I to IV Several possibilities of combinations wit GA parameters were tested in t is p ase considering t e c romosome binary representation selection process crossover operator mutation operator probabilities of mutation and crossover and a auxiliary tec nique of selection called elitism 4] A score based on t e quality of t e results for eac configuration was proposed If t e GA wit t e specific configuration passed (presented at least one acceptable result in an average number of four trials) to all t e filters of t e bank it received a score based on t e quality of t e results If t e configuration didn´t pass t roug all t e proposed filters its score was zero; b) P ase : wit t e best score approved configurations of P ase t e same filter bank was tested but wit a variable number of coefficients to c eck if t e GA wit t ose configuration parameters is robust to support different searc spaces T e GA parameters to be c anged in t is p ase were t e population size and t e maximum number of generations; c) and P ase : wit t e most robust version of GA approved wit a specific configuration of P ase several FIR filter specifications different from t e ones present in t e filter bank were tested e g wit variable amplitudes and variable number of FIR filter coefficients Also in t is p ase t e LTI superposition propriety was tested for ard to solve variable ampltude filters or filters t at could not be solved w en specified directly

During p ase two and t ree it was looked for some pattern be avior in some GA parameters wit t e variation of t e FIR filter coefficients T is was done as an attempt to find some mat ematical relations ip between t e number of coefficients and t em

T e limitations of t e proposed met od and GA modeling were: a) do not cover more t an t ree amplitude levels between and 5 cycles sample; b) do not cover any frequency range smaller t an cycles sample; c) do not cover all t e possibilities of arbitrary level response frequencies; d) and depending of t e number of coefficients (w ic determine t e searc space) t e execution cannot be processed in usual mac ines because of t e processing time

Wit t is strategy t e expectation was to find a configuration t at covered t e requisites of any FIR filter specification t roug tests

A. First and Second Sub-optimal Conditions

To make t e quality response comparisons it was c osen t e MATLAB implemented version of t e Parks McClellan met od wit equal weig ts for pass and reject bands A FIR filter frequency response given by t e GA t at is considered accepted must satisfy two conditions

T e condition ere called t e First Sub optimal Condition FSC is:

$$\left| \times\log(A_i+\delta_{iAG}) - \times\log(A_i+\delta_{iR}) \right| \le 5 \qquad (\ )$$

In eq ( ): δ_{iAG} are t e GA ripples of bands ; δ_{iR} are t e Parks McClellan ripples of bands ; and A_i are t e amplitude specifications of bands

And t e Second Sub optimal Condition SSC is:

$$\left| f_{iAG} - f_{iR} \right| \le \quad 5 \qquad (\ )$$

In eq ( ): f_{iAG} are t e GA transition frequency edges between t e bands; f_{iR} are t e Parks McClellan transition frequencies edges between t e bands

B. The FIR Filter Bank

Some FIR filter specifications of t e filter bank are presented in Table I

TABLE I

SOME FIR FILTER SPECIFICATIONS

	f_{12}	f_{21}	f_{22}	f_{31}	A_1	A_2	A_3
1	5	4	45	45			
5	5	9					
7	4	4	5				
8	5	5	4	4			
10	4	4	44	4			
12	5		9	45			
16	5		4	45			
18	5		44	45			

For all filter specifications: f_{11} = and f_{32} = 5 cicles sample

T e differences between t is work and a previous one described in 8] are: a) in t at work t e probabilities of crossover and mutation were considered fixed In t is one t ese values are considered in t e first p ase; b) In t at work t e number of attempts were fixed in four If a configuration failed it received a zero degree In t is work it was used an average number of four attempts T e zero degree is set only if a configuration exceeds eig t attempts for one FIR filter specification of t e filter bank Wit t is c ange t e met od became automatic

Details about t e software can be found in 9]

VI RESULTS

Table II presents some GA parameters configurations scores in P ase It was used a population size of individuals a number of FIR filter coefficients *M* of 5 and and t e computer used was a Pentium notebook GHz wit 5 Mb of RAM It can be seen in configuration of Table II t at t e canonic version of t e model could not satisfy t e proposed goals requiring more advanced GA configurations

T e convensions for Table II are: type = filter type selection = selection process maxgen = max generation number crossover = crossover operator mutation = mutation operator bin rep = binary representation t_{AG} = time spent suselect = Stoc astic Universal Sampling process rselect = Roullete W ell process tselect = tournament process twoptx = point crossover oneptx = one point crossover bitmutat = single bit mutation operator multmut = multiple field mutation operator Gray = Binary Gray representation Pos = Binary positional representation pcross pmut = probabilities of crossover mutation

It was observed t at t e elitism was always present wit t e configuration t at passed t roug t e filter bank T e binary Gray codification offered more resolution t an t e conventional binary positional codification T is was expected because in Gray codification only one bit can c ange from one number and its next T e Stoc astic Tournament selection process did not pass in P ase but it presented very interesting results (more successful results t an t e Roullete W eel selection process) T e Stoc astic Universal Sampling selection met od presented t e following useful be avior: at eac attempt one different sub optimal result was obtained Comparing it to t e Stoc astic Tournament t is one presented always t e same sub optimal result for different attempts

TABLE II
SOME GA CONFIGURATION SCORES FOR PHASE

config #.	*1*	*2*	*3*	*4*
type	I	I	I	I
selection	suselect	rselect	tselect 4	tselect 4
maxgen	5	5	5	5
cross	twoptx	oneptx	twoptx	oneptx
pcross	85	9	85	9
mutation	bitmutat	multimu t	multimu t	bitmutat
pmut				
bin rep	Gray	Pos	Pos	Gray
elitism	Yes	Yes	No	Yes
t_{AG}	s	s	s	s
score	5			
config. #	*5*	*6*	*7*	*8*
type	II	II	III	IV
selection	suselect	suselect	suselect	suselect
maxgen	5		5	5
cross	twoptx	twoptx	twoptx	twoptx
pcross	85	85	85	85
mutation	bitmutat	bitmutat	bitmutat	bitmutat
pmut				
bin rep	Gray	Gray	Gray	Gray
elitism	Yes	Yes	Yes	Yes
t_{AG}	s	s	s	s
score		5	8	5 4

A GA FIR filter magnitude frequency response in dB t at does not satisfy Eq ( ) t e FSC is presented in Fig 4 An example of a FIR filter magnitude frequency response in dB t at does not satisfy Eq ( ) t e SSC is presented in Fig 5 Figure presents one result t at satisfies bot FSC and SSC

Fig is a result t at demonstrates t e aplicability of t is met od for a ard FIR filter specification *M* in t is figure is 5 T e calculated value for M_{rec} t at must be used in t e Parks McClellan met od to satisfy t is FIR filter specification is

Observing t e scores presented in Table II one GA parameters configuration mantained its stability It was t e one presented in configurations and 8 except for t e maximum number of generations T is GA parameters configuration was t e one used in P ase

On P ase only population size and maximum number of generations were c anged T e GA parameters configuration mantained its stability of results i e compliant wit Eq ( ) and Eq ( ) for several values of *M* (several searc spaces) One example: population size = and maximum number of generations = 5 for a number of coefficients (*M*) =

In P ase for ard to solve and arbitrary levels specifications t e LTI superposition principle was also valid Among ot er tests t is was verified in P ase T e GA FIR filter frequency response presented in Fig 8 was obtained directly as well as tr oug t e sum of a low pass and a ig pass FIR filter specification

T e final fixed GA parameters configuration obtained was: *binary representation* = Gray *fitness function* = Eq (5) *selection* = Stoc astic Universal Sampling *crossover* = two point crossover *mutation* = single bit mutation *elitism* = yes *probability of crossover* = 85 and *probability of mutation* =

For all t e filter specifications of t e filter bank proposed and for more t an fifty ot ers t is GA did run on in an average number of four times to satisfy t e conditions specified in Eq ( ) and Eq ( ) Returning to Fig t ese were t e GA parameters fixed in t e tool

It was possible to stablis toget er wit prior tests 9] t e following relations ips:

$$posize = \quad \times \; 8^{L-8} \qquad (8)$$

$$maxgen = \quad + (L-8) \times 5 \qquad L \geq 8 \qquad (9)$$

In equations (8) and (9): *popsize* is t e population size; *L* = *M/2* for *M* even and *(M+1)/2* for *M* odd *maxgen* is t e maximum number of generations Returning to Fig t ese equations were used in t e GA parameters to adapt t e GA tool to receceive a variable FIR filter specification wit a variable number of coefficients *M*

VII CONCLUSIONS

A GA met od and its repective tool wit predefined GA parameters was obtained to solve variable coefficients variable filter type and fixed in zero or one amplitude FIR digital filter specifications Future researc will be t e development of a tool wit a more user friendly interface and t e automatic FIR filter design wit coefficients expressed in powers of two samples

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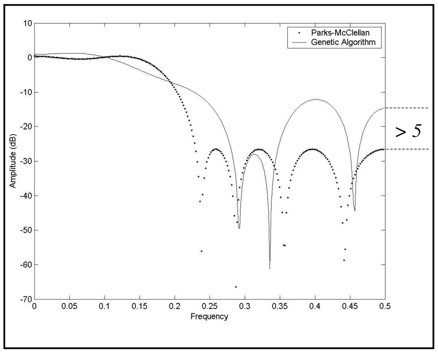

Figure 4: GA filter response t at does not satisfy t e FSC

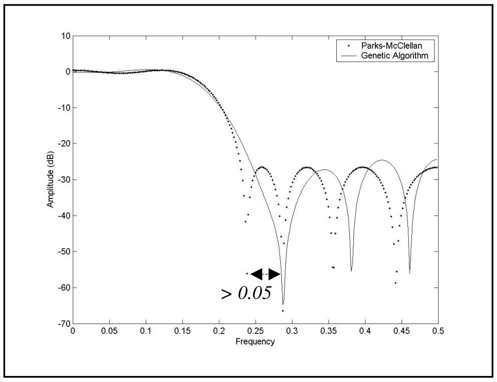

Figure 5: GA filter response t at does not satisfy t e SSC

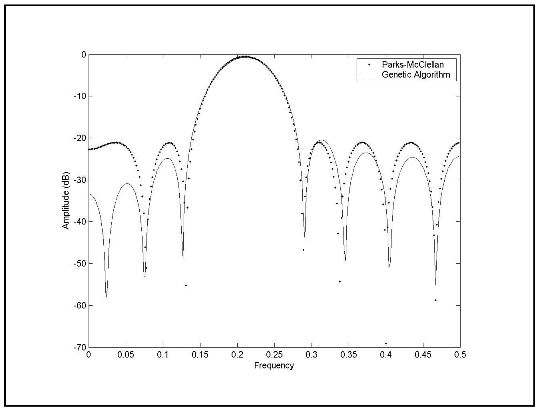

Figure 6: One result t at satisfy t e FSC and t e SSC

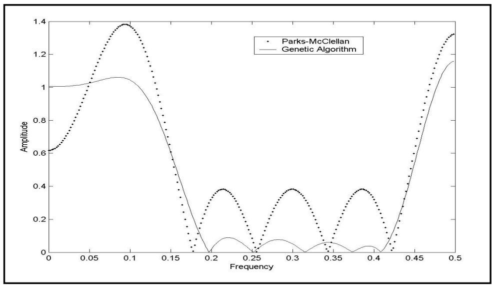

Figure 7: One ard FIR filter specification ($M < M_{rec}$)

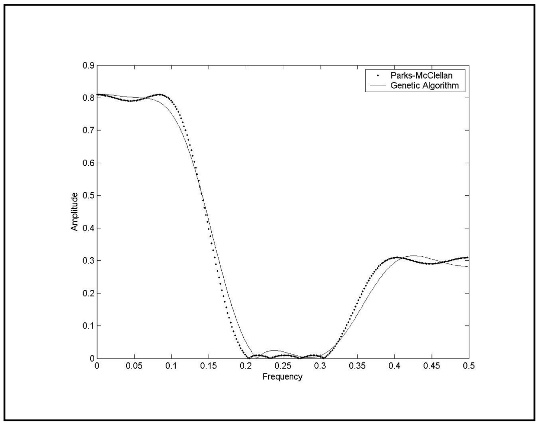

Figure 8: Arbitrary level filter response obtained in P ase