DEVELOPMENT OF THE RULE BASE FOR A DESIGN AUTOMATION SYSTEM FOR SAW FILTERS USING BIDIRECTIONAL TRANSDUCERS

S. M. RICHIE, M. J. McCOLLISTER, and D. C. MALOCHA, University of Central Florida, Department of Electrical Engineering, Orlando, Florida 32816

ABSTRACT

A design automation system, called SAWCOM, has been developed for the noninteractive design and analysis of SAW filters using bidirectional transducers. Such a system increases productivity by reducing filter design time while increasing design accuracy. The SAWCOM system takes as input a high level performance specification of the SAW filter to be designed, as well as parameters pertaining to substrate availability and fabrication capabilities, and then begins a synthesis-analysis-verification cycle which continues until all design alternatives are found which meet the specifications, within the constraints of the SAWCOM system. As the means for determining the filter's design parameters, the system uses a set of design rules implemented in the PROLOG language. The system's design rule base relates design and analysis parameters, which include parameters such as substrate choice and other material parameters, structural organization parameters such as the weighting technique, and transducer parameters such as the sampling rate. The design rules provide an implementation of the necessary design curves and relationships and allow for the possibility of an exhaustive check of design solutions. The SAW filter parameter relationships included in the design rules allow the design automation system to iteratively correct in a closed loop design process for nonideal device behavior, such as passband distortion due to electrode charge effects and electrical equivalent circuit model effects.

This work was funded in part by the Florida High Technology and Industry Counsel.

1.0 Introduction

A design automation system for SAW filters should have as input a frequency domain description of the desired device response, parameters for fabrication capability, and allowed design variations. After synthesis and analysis, the structural description of the device layout for a photolithographic mask should be output. The implementation of such a system requires the following capabilities. First the device synthesis algorithms and techniques must be implemented with special consideration for the application to SAW filter transducers. Next, the device analysis models must exist. Finally, the design automation shell software must be developed to exercise the synthesis and analysis CAD system noninteractively. The design automation software must include not only the SAW filter design rules but also the necessary data parameter extraction and execution control tools. This strategy has dictated the architecture of the current system discussed here, called SAWCOM [1]. The implementation consists of a system which has a core of FORTRAN device synthesis, device analysis, and network analysis modules, a set of C interface and data manipulation modules, and a PROLOG SAW filter design rule module. These modules then communicate information via system files and are all controlled by a shell module which orchestrates the design automation. Figure 1 illustrates this architecture. The design automation system is designed to operate on an IBM-PC or compatible personal computer with 640K RAM installed, an Intel 80x87 numeric coprocessor, and VGA display capability. The finite impulse response (FIR) synthesis tools, bidirectional transducer analysis tools, and device response calculation tools have been integrated in a menu driven interactive system called SAWCAD-PC [2].

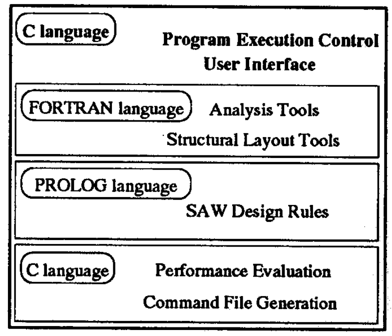

Figure 1 - System Code Architecture Diagram.

2.0 Design Automation Shell

In creating the design automation system, six functional modules were developed to perform the necessary information processing. The data file naming convention and the files which are input and output by each module are shown in Figure 2. Each of these modules represents a separate executable program which may be run internal or external to the design automation system. The only user interaction in the device design cycle of the design automation system is in the specification of the filter's performance parameters. This interface is implemented in the module code of SIO.C, which is a C language program.

The FIR weighting functions are synthesized using the routines of SAWCAD-PC. The design automation system takes advantage of the I/O redirection capabilities of the PC-DOS operating system in the control of the execution of SAWCAD-PC. From the data contained in the data files generated by the filter specification program, SIO.C, and the design rule program, SDR.PROLOG, another module, BLD.C, builds the command sequences necessary to generate the filter's FIR weights. This module also includes the distortion compensation calculations and therefore takes as input data from the response examination module, EXA.C. The BLD.C module has the responsibility of determining when the designed frequency response has satisfied the design specifications.

Due to the partitioning of the design automation functions and corresponding code, each module's performance and capability may be extended and verified by use in a manual interactive mode. The automation shell of SCM.C will then use these extended capabilities since they are transparent to the control

1051-0117/90/0000-0155 $1.00 © 1990 IEEE

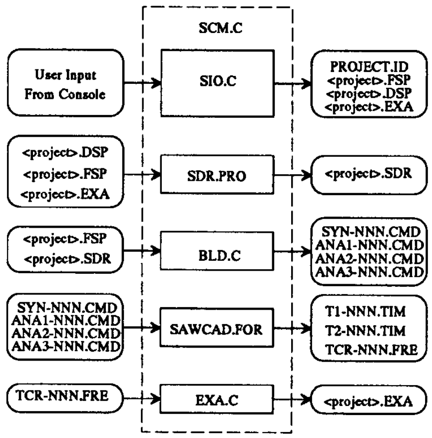

Figure 2 - SAWCOM Modules File Communications.

structure. This represents a significant advance over a manual design system and will be very important in CAD/CAM for industrial applications.

3.0 Design Rule Development

In certain cases the task of relating device specifications to design and analysis parameters is straightforward and can be automated easily. Other design parameters can be solved iteratively by executing a synthesis-analysis-evaluation cycle and terminating upon convergence to the design parameters which yield performance that falls within a given set of specifications. The task of identifying the design rules requires the definition of the relationships between such design parameters as the synthesis procedure, device structure, transducer layout geometry, and material choice. Of course, not all parameter combinations are possible. For example, certain synthesis techniques are only appropriate for implementation with specific device geometries and on certain materials. Once the filter has been designed and analyzed, the frequency response often contains distortion artifacts which are the result of such device characteristics as the electrical port transfer function and the nonideal sampling nature of the induced charge function. While these effects can be accurately modeled, they cannot in general be included in the synthesis algorithms. These effects are then compensated for by iteratively predistorting the synthesis functions until their effects have been satisfactorily minimized. Such an iterative compensation method is ideally suited for automation and can generally yield results which are equal to or better than that from a manually executed solution.

One purpose of the work presented here is to demonstrate the feasibility of using design rules in the implementation of a SAW filter compiler. An exhaustive set of design rules has not been defined, and further work in this area is continuing. In order to identify the design rules to be used by SAWCOM, a set of design and performance parameters was identified and then classified by function and origin. The parameter class *origin* is used to designate the source of the parameter's definition. The parameter class *function* is used to designate the parameter's actual use. Table 1 contains a list of the SAWCOM design and analysis parameters and Table 2 a list of parameter dependencies.
The members of the class *origin* are:

1 - User Defined (designated user_defined)
2 - Inferred from User Defined (designated inferred)
3 - Defined from Design Rules (designated design_rule)
4 - Calculated from Analysis (designated analysis).

The members of the class *function* are:

1 - Performance Specification (designated performance)
2 - Physical Specification (designated physical)

Table 1 - SAWCOM Design and Analysis Parameters

Parameter	***Function***	***Origin***
acoustic beam width	physical	design rule
aperture resolution	performance	design rule
break locations	physical	analysis
center frequency	performance	inferred
coupling coefficient	physical	inferred
device dimensions	physical	analysis
effective permittivity	physical	inferred
external components allowed?	physical	user defined
fractional bandwidth	performance	inferred
frequency magnitude response	performance	analysis
frequency magnitude template	performance	user defined
frequency magnitude tolerance template	performance	user defined
frequency phase response	performance	analysis
frequency phase template	performance	user defined
frequency phase tolerance template	performance	user defined
frequency resolution	performance	design rule
insertion loss	performance	analysis
maximum device dimensions	physical	user defined
maximum group delay	performance	user defined
maximum insertion loss	performance	user defined
metal resistivity	physical	inferred
metal thickness	physical	user defined
metal type	physical	user defined
minimum group delay	performance	user defined
minimum metal to edge	physical	user defined
minimum rejection level	performance	analysis
package availability	physical	user defined
package type	physical	design rule
pass band slope	performance	analysis
passband ripple	performance	analysis
pin assignments	physical	design rule
sampling rate	performance	design rule
shape factor	performance	inferred
structure	physical	design rule
substrate	physical	design rule
substrate availability	physical	user defined
substrate velocity	physical	inferred
temperature range	performance	user defined
transducer #1 FIR weights	performance	analysis
transducer #2 FIR weights	performance	analysis

Table 2 - SAWCOM Design Parameter Dependencies

Parameter	Dependencies
acoustic beam width	frequency magnitude template, insertion loss, coupling coefficient, external components, maximum device dimensions, structure
break locations	transducer#1 FIR weights, transducer#1 FIR weights, structure, acoustic beam width
center frequency	frequency magnitude template
coupling coefficient	substrate
effective permittivity	substrate
fractional bandwidth	frequency magnitude template
frequency magnitude response	global
frequency phase response	global
insertion loss	global
metal resistivity	metal type, metal thickness
minimum rejection level	global
package type	package availability, device dimensions
pass band ripple	global
pass band slope	global
pin assignments	package type, structure
sampling rate	center frequency
shape factor	frequency magnitude template
structure	shape factor, fractional bandwidth, substrate, maximum device dimensions, maximum insertion loss
substrate	temperature range, passband width, insertion loss
substrate velocity	substrate
transducer #1 FIR weights	frequency magnitude template, frequency phase template, maximum group delay, maximum insertion loss, sampling rate
transducer #2 FIR weights	frequency magnitude template, frequency phase template, maximum group delay, maximum insertion loss, sampling rate

To illustrate the design rules as implemented in PROLOG, Figure 3 gives a partial program listing of SDR.PRO showing the rules for

```
/* sampling rate */

sampling_rate(2, Fo, Min_line_width, Substrate) :-
    get_v0(Substrate, V0),
    Lambda0 = V0 / Fo,
    (Lambda0 / 8) <= Min_line_width.
sampling_rate(4, _, _, _).

/* substrate */

substrate(Substrate, Fs, Frac_bw) :-
    get_k2(Substrate, K2),
    Np = 2 * Fs / Frac_bw,
    K2 > 3.14159 * Fs / (2 * Np * Np).
```

Figure 3 - Code Segment From SDR.PRO

4.0 Synthesis and Analysis Capabilities

Several FIR synthesis techniques have been included in the synthesis tools of SAWCAD-PC and are therefore available to the SAWCOM system [3,4,5]. The charge superposition model is used to predict the transducer's electrical effects and the acoustic response from the induced static charge function [6,7,8]. The calculation efficiency of this approach and its ability to account for all first order effects and some higher order effects has led to its choice as the approach used in the design automation system for analysis of the SAW filter's transducer response.

5.0 Example Execution

An example execution of the design automation system is shown to illustrate the capabilities of the system. Figure 4 shows the initial screen and the SAWCOM options list. The first two options concern the execution of the design automation system, while the remainder of the included options are for system support and convenience. A design begins by first specifying the frequency domain template for the filter's transfer characteristics. This is done by selecting the "input device specifications" option from the SAWCOM options list. This causes the input screens to be displayed as shown in Figure 4 and Figure 6. The filter's center frequency is 150 MHz and a sampling rate of $4f_o$ is used. The passband width is selected to be 15 MHz and a rejection bandwidth of 18 MHz is defined. This yields a design with a shape factor of 1.2. The only allowed substrate are defined to be YZ-$LiNbO_3$ and ST-Quartz.

The automated design process is initiated by selecting the "execute design procedure" option. The console display then shows the screen display as if an external user were executing the design. The SAWCAD program and the other design automation modules are used in solving for an acceptable solution. Once the specifications have been met, control is then returned to the SAWCOM options list. The data for all iterations is saved to disk such that the system's performance may be evaluated.

After the design rules have been exercised, an initial list of possible combinations of solutions is generated. This initial parameter list is then used to synthesize and analyze different SAW device alternatives. When done the SAWCOM system finds all design solutions to the problem specifications, within the constraints of the SAWCOM parameters. Figure 7 shows the results of considerations of the design rules determination of the SAW device structure, substrate choice and transducer sampling rate.

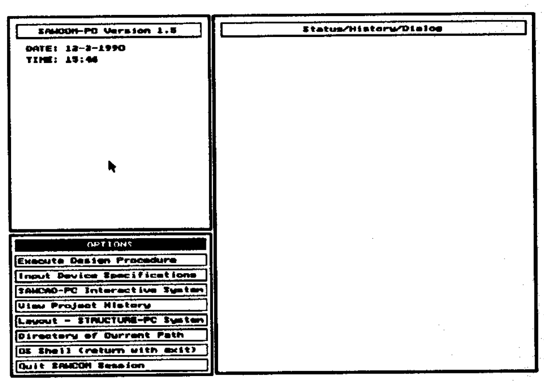

Figure 4 - SAWCOM Introductory Screen.

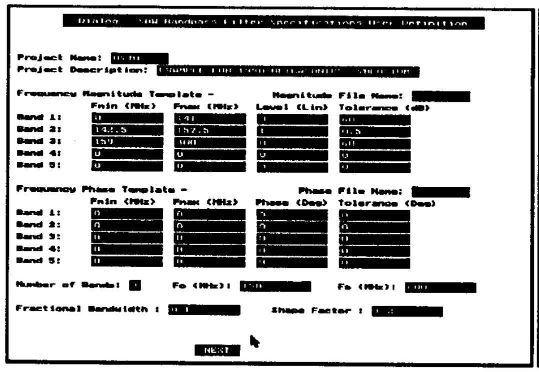

Figure 5 - SAWCOM User Definition Screen Number 1.

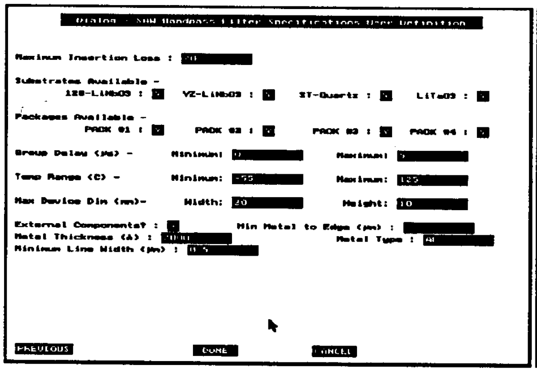

Figure 6 - SAWCOM User Definition Screen Number 2.

6.0 Conclusions

Around the synthesis and analysis tools of SAWCAD, a design automation shell, called SAWCOM, has been demonstrated and further development is continuing. This shell is capable of noninteractive filter design from an initial set of filter performance specifications. The highest level design alternatives are chosen from a consideration of a set of design rules. This system allows the system design and analysis loop to be closed in an automated fashion and can now serve as a platform for the continued development and extensions of more sophisticated and in-depth design rules. As more complete and interrelated design rules are established, they may be easily added to those which exist in the present system. The scope of the design rules may also be expanded to include the necessary parameters to completely define the layout and mask data for a SAW filter production device. The models for the second order effects not accounted for may be included in the analysis tools without affecting the other existing system components when such models exist in a compatible form. The shell-tool architecture of the SAWCOM system is designed to accommodate such development efforts. Design automation systems play a key role in the continuing effort to increase device design efficiencies and device performance.

```
structure____= uniform_uniform
substrate____= linbo3_yz
sampling_rate= 4

structure____= uniform_withdrawn
substrate____= linbo3_yz
sampling_rate= 4

structure____= uniform_apodized
substrate____= linbo3_yz
sampling_rate= 4

structure____= withdrawn_apodized
substrate____= linbo3_yz
sampling_rate= 4

structure____= withdrawn_withdrawn
substrate____= linbo3_yz
sampling_rate= 4

structure____= apodized_msc_apodized
substrate____= linbo3_yz
sampling_rate= 4

structure____= uniform_uniform
substrate____= st_quartz
sampling_rate= 4

structure____= uniform_withdrawn
substrate____= st_quartz
sampling_rate= 4

structure____= uniform_apodized
substrate____= st_quartz
sampling_rate= 4

structure____= withdrawn_apodized
substrate____= st_quartz
sampling_rate= 4

structure____= withdrawn_withdrawn
substrate____= st_quartz
sampling_rate= 4
```

Figure 7 - Results Execution for Design Rule Subset

References

[1] Richie, S. M. and Malocha, D. C. "A First Generation CAD Compiler for Surface Acoustic Wave Filters Using Bidirectional Transducers." *IEEE Ultrasonics Symp. Proc.*, 1989.

[2] Richie, S. M., Abbott, B. P., and Malocha, D. C. "Description and Development of a SAW Filter CAD System" *IEEE Trans. Microwave Theory and Techniques.*, vol. 36, no. 2, pp. 456-466, 1988.

[3] McCellan, J. H., Parks, T. W., and Rabiner, L. R. "A computer program for designing optimum FIR linear-phase digital filters." *IEEE Trans. Audio Electroacoust.*, vol. AU-21, pp. 506-526, 1973.

[4] Malocha, D. C. and Bishop, C. D. "The classical truncated cosine series functions with applications to SAW filters." *IEEE Trans. Ultrasonics, Ferroelectrics and Frequency Control*, vol. UFFC-34, pp. 75-85, 1987.

[5] Vasile, C. F. "A numerical Fourier transform technique and its application to acoustic surface wave bandpass filter synthesis and design." *IEEE Trans. Sonics and Ultrasonics*, vol. SU-21, pp. 7-11, 1974.

[6] Morgan, D. P. *Surface-Wave Devices for Signal Processing*. New York: Elsevier, 1985.

[7] Hartmann, C. S., Bell, D. T., and Rosenfeld, R. C. "Impulse model design of acoustic surface wave filters." *IEEE Trans. Microwave Theory Tech.*, vol. MTT-21, pp. 162-175, 1973.

[8] Datta, S., Hunsinger, B. J., and Malocha, D. C. "A generalized model for periodic transducers with arbitrary voltages." *IEEE Trans. Sonics and Ultrasonics*, vol. SU-27, pp. 235-242, 1979.