THE PRINCIPLES OF CREATION OF COMPLEX DISCRETE SIGNAL CAD SYSTEM.

ICAS-92-7.1R1

S. V. Bichenkov
Moscow Aviation Institute
Moscow, Russian Federation

Abstract

This article discusses the basic principles of creation of CAD system for developing complex discrete signals (CDS) with consideration for special features of the radioelectronics area, where CDS are explored. During discussion, various kinds of CAD support, such as information and mathematical support, hardware and software, are analyzing. Particular emphasis has been placed on mathematical support and software.

I. Introduction.

Complex discrete signals are widely used in up-to-date radiosystems of different applications and particularly in satellite radiosystems. These signals have a very long baseline and are based on M-sequences and Gold codes. CDS usage allows to successfully satisfy such high and conflicting objectives for radiosystems as a noise-immunity of information transmition and an accuracy of delay and Doppler measurements. The application of code sequences and above all M-sequences and Gold codes allows to realize a great number of safely separated channels (addresses) with a reliable synchronism approach in asynchronous-multiplex systems. Most of the radiosystems with CDS (later on radiosystems) are widely distributed in such spheres as communication, telecommunication, control, navigation, location and so on. A role and importance of these radiosystems are continuously growing with increasing of requirements, functionalities, reliability, and accuracy. In this connection structure and design trajectory of radiosystems are rapidly complicated.

The radiosystem's structure is mainly determined by used signals, that's why selection of a signal system (assembly) is the first difficult stage of the radiosystem design. While deciding this problem traditional methods require a lot of computations and spend a lot of time, what increases a prime cost of the radiosystem or make soften the objectives. But mainly it is very hard to automate the design trajectory using these methods. In connection with this there is a new promising approach presented in the articles[3,4], where an author basing on algebra's features of code sequences suggested effective algorithms. Their application can provide an easy automation of CDS design trajectory with using powerful interactive means of personal computers (PC). Due to this approach a number of searching variants has been decreased considerably, what can give more illustrative computation results and control decision-making process actively. However the application of the effective algorithms requires special knowledge and habits from a designer.

In the context of the mentioned problems it is seemed to be worth while to pick out CDS design stage from the radiosystem's design trajectory as a separate direction based on an application of a specialized CDS CAD system.

II. Information support of CDS CAD.

Information support or dataware of CDS CAD consists of input data, which are presented in a special form for the future processing, output data or design decisions, intermediate data and data processing tools. During CDS CAD design it is useful to foresee an opportunity of accumulating various data in a database to rapidly increase the decision-making of standard tasks. Besides that, all data and methods, which are connected with CDS exploration and are integrated in CDS creation process, are related to information support also. Usage of a commercial database is seemed to be not effective, so as most of the universal database's means will be not used and some problems will appear connecting with database integration into CDS CAD.

Input data for CDS CAD are getted from an analysis of technical job. Most often input data are the same: 1) an adequate measurement accuracy, 2) a coverage range, 3) a carrier frequency, 4) a message transmition speed, 5) a number of transmitted messages, 6) a number of channels in a multiplex radiosystem, 7) antenna characteristics, 8) adequate loss and some other data.

During radiosystem synthesis it is demanded to get the following output data from CDS CAD: 1) a length of a pseudo random sequence or a capacity of a shifter, 2) signal acquisition (integration) time, 3) a number of addresses (a size of assembly), 4) ambiguity area of searching a frequency and delay.

During radiosystem analysis CDS CAD must perform a role of a simulation environment, results of which operating are uncertainty functions, such as one- and two-dimensional, auto-, cross-correlation and ambiguity functions, statistical and extreme parameters of signal assemblies.

III. Mathematical support of CDS CAD.

Mathematical support of discussed CDS CAD is based on equations and conclusions, presented in [2,3] and obtained with a help of the algebraic coding theory. Namely these equations and conclusions allow to decide the main problem of CDS design, consisting of the great number of counted CDS variants.

The main operation being used during CDS synthesis and analysis is M-sequence generation, which traditionally is realized by the shifter with modulo-two adders in a feedback circuit. The shifter's flowchart is presented in the figure 1, where $c_0, c_1, \ldots, c_{n-1}$ are factors of a generating polynomial ($c_i = \{0,1\}$, $i=0,1,\ldots,n-1$), $X=\{X_0, X_1, \ldots, X_{n-1}\}$ is a beginning sequence, Z is an output sequence with a length $N=2^{n-1}$.

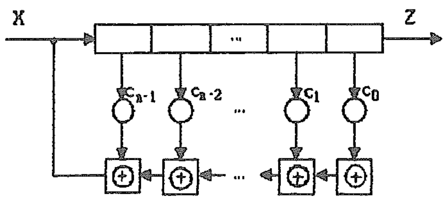

Figure 1. The flowchart of the shifter.

Another basic operation is the count of two-dimensional cross-correlation function (CCF) θ_{ab} of sequences a(i) and b(i) with a length N:

$$\theta_{ab}(\tau) = \sum_{i=0}^{N-1} a(i+\tau)\, b(i) \qquad (1)$$

The analysis and selection of M-sequence assembly assume CCF computation of all paires of sequences for all integer values of τ. Applicative CDS have a baseline up to $N=2^{22}...2^{25}$, that's why the decision of this task by an exhaustive search is not compatible with CDS CAD application at PC.

The way out was found in the new approach, which is suggested in the papers [2,3] and based on the following equations and conclusions.

1. M-sequence structure may be defined by selecting $\alpha \in GF(2^n)$, where $GF(2^n)$ means the Galua field and α means the Galua field's primitive. The beginning sequence is generated by the polynomial with a root α.This sequence is number 1 for any n, and the polynomial may be found in tables[5]. M-sequence number k with other structure may be gotten by taking selections of the beginning sequence with a step k. The generation of k-numbers is organized by an algorithm (k,N)=1 (all k-numbers copriming with N).

2. Under CCF's computation one cannot search al τ-values, but only τ-values from a set of adjacent classes' leaders, which are the minimum meanings of the group $\{\tau_m, 2\tau_m, ..., 2^{q_m-1}\tau_m\}$, where q_m is a degree of the corresponding polynomial, $m=1,2,...,k, j=0,1,...,n-1$.

3. For CCF of M-sequences, which have roots $\beta = \alpha^1$ and β^k:

$$\theta_\beta(\tau) = \theta_\alpha(\tau 1). \qquad (2)$$

In other words, it is sufficient to limit the count of CCF of all M-sequences by those pairs, where one beginning sequence is fixed.

4. If look (2) under the condition:

$$lk = 2^j \ (\mathrm{mod}\ N), \qquad (3)$$

then:

$$\theta_\beta^k(\tau) = \theta_\alpha^1(-\tau) \qquad (4)$$

It excepts a half of remained pairs.

5. Some assemblies of M-sequences or Gold codes can have levels larger or equal N/3. The obtained results [3] allow to detect the sequences with a length $N=2^{2p}-1$ and with such extreme levels beforehand and to except the corresponding sequences from the searched set. In this case under the adequate correlation level of CCF $\theta_{adeq} \ll N/3$ the exception of only one "bad" pair decreases the size of assembly at least twice in the comparison with the whole number of sequences with a length N.

Basing on the reduced equations economical and speed algorithms were worked out and run on IBM PC AT.

Another part of mathematical support is a set of algorithms of signal processing into radiosystem blocks, such as a generator, modulator, demodulator, correlator, matched filter, etc. Besides that, there are algorithms of information representation and display under CDS design, which are related to mathematical support also. This part of mathematical support is well known for CAD designers and not presented in the article.

IV. Hardware of CDS CAD.

Hardware of CAD depends on a complexity of design problems probably more, then other kinds of CAD support. That's why CAD hardware may have different applicative forms starting from alone professional PC and right up to a powerful distributed computer network. CDS CAD, which is aimed to be useful during design of rather complex radiosystems, can work either at a workstation or at alone PC. At the last case the design will be more cheaper, but it is ought to have appropriate mathematical support, which not requires the great resources of mainframe or workstation. Such mathematical support was mentioned above, that's why one can apply CDS CAD at professional PC. During the selection of PC it is ought to call attention to compatibility or transportability of available mathematical support and software. The most popular representatives of professional PCs are IBM PC AT and PS/2. PCs have a configuration, which may be standard or not. The standard configuration consists of a system block with its microprocessors and controllers, a keyboard, a video system (adapter and monitor), a mouse and a printer. The optional configuration of CAD hardware may include various pads, scanners and plotters. The term "standard" is conditional because of great difference between various realizations of standard devices made by different manufacturers. As you can see after reading the whole article, the standard PC's configuration is anougth for CDS CAD system.

V. Software of CDS CAD.

On the whole, CAD software consists of two parts: a system part and an application. The system software, which also called as operational environment, consists of operating system (MS DOS or PC DOS for IBM PC AT) controlling the user interface, integrator, database and system, which may be named as computer-aided software engineering. In our case the application software reflect the concrete peculiarity of CDS and CDS CAD. The last usually contains its own user interface and probably integrator and database. During CDS CAD design it is ought to call attention to conformity of international standards, such as

ISO, IEEE, X11, EDIF and others. Commercial CAD system forms a software package.

The structure of CDS CAD software package.

One can conditionally imagine the structure of CDS CAD software package as a system of three blocks: 1) a modeling block (MB) computating functional parameters and characteristics, 2) a control block (CB) organizing the interaction between a designer and CAD, and between separated blocks within CAD, and 3) a service block (SB) supporting user work and processing of the MB and CB. All these blocks play an equally important role in CDS CAD operating: the CB is the center interconnecting unit, the MB allows to get the design decision and the SB takes its part in forming a view of software package from a user standpoint. Figure 2 illustrates the general structure flowchart of CDS CAD.

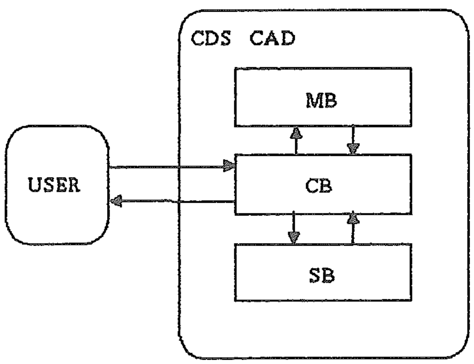

Figure 2. The general structure flowchart of CDS CAD.

This flowchart corresponds to such principles as open-ended system organization and structured programming. Every block is designed separately and independently, and all of them are divided on smaller blocks, the last are divided in their turn and so on right up to indivisible program modules, realizing basic operations such as various computations, input/output, printing, etc. Usage of the documented library structure can easy optimize CAD under new requirements, specific applications, various hardware and software, concrete user tasks, what increases the effectiveness of CAD operating and design. The library structure may be organized by two ways. The general, control and specific program structures of CAD are based on designer's and programming system's libraries. In this case the finished software package version is compiling and linking anew after every modification of these structures. Another way is a run-time library, with help of which a user can integrate user-defined executable programms with a commercial package to decide his private tasks. Besides this, detailed documentation, total or partial distribution of CAD in the form of source code, standard object or library programms one can allow to effectively configure CAD system with higher degree of an error detection and correction.

One can distinguish three hierarchical levels into the MB. The fist highest level reflects system methods of the design in the investigated sphere. This system methods (the MB modes) are the synthesis and analysis of M-sequence assembly. It is a very hard to formalize these methods, especially the analysis, because of great number of CDS available for one radiosystem and also because of different radiosystem blocks' flowcharts. That's why these modes are divided into smaller structures, which conditionally may be called as models. The models characterize signal generation and processing by various parts of radiosystem. Due to models a designer can estimate intersymbol and radio influences and make the corresponding conclusions. One of the models include or use the others, some models can interact with the models of the other modes or with the CB and SB. Every MB mode contain a description of the models, from which it consists. The interaction between the MB models and the SB is organized by the CB, which forms (with a help of a user) the design trajectory. For all this the MB and SB can "know" nothing one about another. That is easy to realize organizing the SB structure like the MB one and foreseeing the CB's access to the modes-descriptions of the MB and SB. Thus, the MB and SB modes are the submodes of the CB.

The model is characterized by a set of operations, being fulfilled under the modeling. The operations reflect nor functional particularities of various parts of radiosystem (as the models do), but methods and algorithms, used under the design process. They are not divided further and are realized in the form of loaded modules, executable programms and overlay routines. The operations are characterized by their algorithms and used data and present the third hierarchical level of the functional blocks (the MB and SB) of CDS CAD. So, the more defined flowchart of CDS CAD one can see in the figure 3.

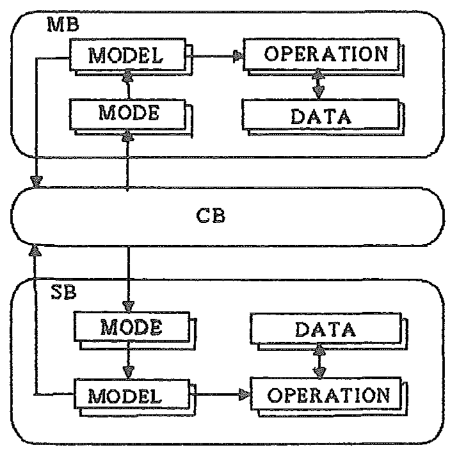

Figure 3. The more defined flowchart of CDS CAD.

In the figure 3 the modes are descriptions (data with lexical and semantic meanings), the operations are the executable codes or library routines, data are input, output or intermediate data, and what are the models? Three variants are possible: a description, a code and a combination of them. In the first case CDS designer has a powerful tool for creating new models or modifying the old ones, so as he operates with well known categories "what to do" and doesn't take care of "how to do". However, CAD structure becomes more complex because of mechanism of a lexical and semantic analysis, and the CB loading increases. It the second case, when model is a code, one can rapidly win in CAD speed, but loose flexibility and visuality under CDS design. The optimal decision one can find in the third form of the model organization. In this case the first variant is more related with the MB and the second one with the SB. So, CDS developer will get a powerful design tool and high-performance service.

As you can see from the figure 3, the flowchart is redundant, because of operations and a lot of data, which are the same for both blocks, for example, file reading and writing operations, input technical and tacticle data, computed values of the uncertainty functions and other data, needed for the modeling so as for the display and documentation. Otherside, it is comfortable to have a united mechanism of the creation and modification of data and operations. That's why one can take out operations and data from the functional blocks' hierarchy and place them into an additional block, which is called database (DB) and connected with the CB. It is comfortable to store the design decisions' results into DB. The detailed variant of CDS CAD flowchart is shown in the figure 4.

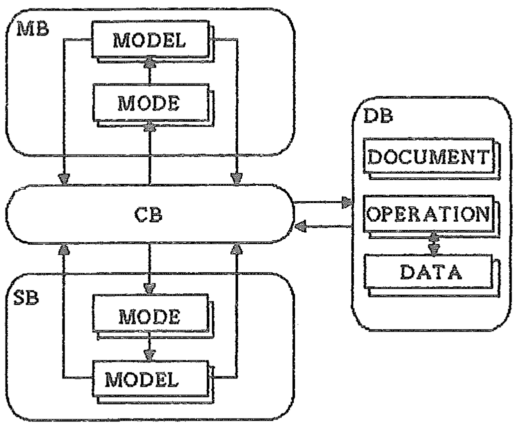

Figure 4. The detailed variant of the flowchart of CDS CAD.

The modeling block of CDS CAD.

The MB is intended for the computation of the M-sequence structure, for the analysis and selection of CDS assembly, which has the required or best qualities. These system modes are based on the models. The algorithm of each model depends on the kind and combination of the design objectives and uses the set of the basic indivisible operations applicable during CDS design.

There are two main modes: 1) the synthesis of code sequence assemblies and the best one's selection, and 2) the analysis of the assembly's satisfaction of the required objectives. Moreover there are some additional modes: 1) recount and redefining of the input data for the direct usage by the models, 2) data and results acquisition and 3) the analysis of the exist design decisions corresponding with the input data.

The existing of the different conflicting objectives being produced to CDS, so as a lot of CDS and radiosystems' schemes defines next lower hierarchical level, which consists of the models. There are some formalized models common for various radiosystems, such as the model of the optimal signal reception with correlators or matched filters. The most common operations are the M-sequence generation and the computation of the uncertainty functions.

Under CDS CAD development much attention must be given to graphic visualization of the computed results with a user interaction. Particularly it's very important under displaying the uncertainty functions, when a designer must research 2D- and 3D-graphs in detail. In this case it is ought to foresee the opportunities of image scaling, moving, rotation, manual or object-oriented highlighting of levels, areas and sections, display and comparison of several graphs on a screen and so on. The computer graphics is not related with the radioelectronics or algebraic coding, that's why it is worth while to place graphic routines into the SB and to control them by the MB models. The highquality graphic user interaction is the center part of CDS CAD, so as namely this interaction allows to raise the effectiveness of the design decision up to more quality level in the comparison with the traditional methods. In connection with this let's look one computer-aided CDS design method, corresponding to such level. CDS radiosystems work for many years, and there are many tables containing a lot of generator polynomials with such parameters as a length of a pseudo random sequence, an integration interval and others. Mostly the polynomial's selection is random or based on developer's experience. Then the optimal uncertainty function (mostly CCF) counted by a fully or nearly exhaustive search at the powerful computer for about a week. But really the technical decision will not be optimal under this. The optimization are held by adding unoptimal requirements and then investigating the delicate CCF's structure under these requirements to find narrow spikes with a help of the interactive graphic display of CCF. In this case a developer using an abstract thinking, an experience or by intuition is able to highlight "bad" (from his point of view) CCF's areas, analyze them, change the assembly or the polynomial, highlight again and so on up to taking the final decision about those or other polynomial and assembly. Besides that, the optimal in the wide range CCF is not needed always, and it may be not optimal at all, but optimized in the defined narrow range. It is impossible to formalize such optimization, but it is easy to do it due to the flexible interactive visualization on PC's screen.

The detail looking of the MB programming, so as the other blocks, is beyond the scope of this article. Only several moments, which may be usefull in practice, will be touched.

At fist it is worth while to use PC's registers under the programming of the shifter. Modern microprocessors, for example i80386 and i80486 of the later modifications of IBM PC AT, contain 32-bit data registers, that's anouth for the shifter's modeling. Besides, one can emulate the 32-bit model upon the 16-bit microprocessors (i8088/286) with small additional programming efforts and more slow speed. At least one can use multi-bit coprocessors. The feedback circuit may be formed by the other data register as a bit mask, when bits with the meaning "1" indicate the feedback chains. Than the bit handling being written on the assembly language allows to achieve the maximum speed.

The second moment is connected with the generating polynomial input. Not every polynomial generates M-sequence, that's why one can waste for several hours due to only one incorrectly inputed character. So it is necessary to check the polynomial input. A good variant is the graphical input with the usage of icons. Such input allows to decrease the probability of an error, which can occur due to user tideness or inattention.

The third moment is, that the mentioned above the algebraic description does not require input of all the available generating polynomials, operating only with their roots. It is allow to automatically form all the polynomials' structures allowing user simply select one of them. Due to this the effectiveness of designer working becomes higher and special knowledge aren't needed.

The control block of CDS CAD.

The CB is responsible for organization of information streams into CDS CAD, so as for control of the system modes, because of similarity of these functions.

Information streams may be in two forms: commands and data. The commands are received by the CB from the models and inform about some situations requiring an activity of the CB (e.g., *request for information or operation call*). The commands may be realized by the different ways from jumping to an entry of the CB and up to setting of a system flag. The first is more simple, but the second is more descriptive.

The data streams are more various and play more important role. The first data stream, with which the system starts to operate, is an input stream from a user named by a user interface. Namely it forms user's estimation of any commercial software. A user has two opportunities of interacting with the program: a dialogue or batch mode. The batch mode of CDS CAD operating is possible (but improbable) at the stage of CDS assembly generation, which algorithm is formalized and the counting is rather long. However nothing must prevent user to input data manually in the dialog mode. The organization of man-machine interaction combines a hierarchical menu system, context help and examples of solving problems. The methods of this organization are widely known, for example popup, pulldown, full-screen or continuesly presented menu, crossed or uncrossed windows, hierarchical tree, icons reflecting the current system task and state, a hot-key system and so on. The points of menu may be textual or graphic, with highlighted or underlined key symbols, in the form of icons being selected by a keyboard or a mouse. The MS Windows may be looked as a standard for user interface. The developed software widely use graphics and present the opportunity of menu system configuration, such as change of colors, size placement of windows and menu bars, change of interaction speed in the wide range and so on. Some systems, which have musical support, also have a great gain. The modern programms don't sensible to random errors of the user input and aromatically check input data. In order to simplify the CB structure it's worth while to display the results and data by the SB, and to retain as the CB function the output of messages about system operating errors.

The other data stream is an internal stream of data between the models of the MB and SB and between the models and the database. Such data are determined in the descriptions parts of the models. The output data are accepted from the models' outputs as corresponding commands become available and then they are placed into the database. The input data and operations pass the opposite way. Note, that operations more actively process data than models and can have a direct access to data, so as operations and data are contained in the united structure forming them.

Except information streams the CB controls CDS CAD modes. In more exact terms the CB controls the sequence and interaction of executable modules, of which operations and models are consists, and dispatches the available PC's memory. The dispatching depends on the operating system of PC, the complexity of CAD hierarchy and the designer's capabilities.

The mentioned above CB mode of the lexical and semantical analysis takes one of its simple forms in the case of CDS CAD. Any system mode consists of the description containing the models' names, a sequence and combination of which reflect the applicable design methods. Any model has the similar description structure containing names of the usefull models, operations and data. This description also contains an algorithm, by which the usefull models and operations are activated. Such algorithm-description may be realized on a predicate language. The CB continuesly picks out name by name, compares them with the known ones stored in a special vocabulary into the database, suggests a user to input unknown data and integrate unknown models and operations, and activates the model. Under the operating the CB analyzes the commands and the output data to handle the operation process in order with the algorithm-description.

The principle of the CB creation radically differs from the models' creation of the functional blocks. The CB is a run-time environment, which doesn't allow to modify its structure by CDS CAD user. The CB operation must be so quick and so simple for a user, as he doesn't distract the attention from the main aim of design.

The service block of CDS CAD.

Usually a term service means suggestion of redundant means, which are not directly related with the main purpose of the system, but increasing the comfort under operating with it. From the point of effectiveness of CAD operation and development, it is comfortable to add low-level implemented routines handling hardware to the SB functions. It allows to use the best capacities of PC and to simplify CAD structure.

A powerful service makes personel job easier and aims a potential user to buy a concrete CAD system. Such service means the opportunity of PC architecture adaptation, to get two-dimensional and three-dimensional color graphic displays of results, to widely change color, type and scale of displayed graphs and pictures, to create new and edit old patterns, to investigate a delicate structure of graphs, to make statistical data processing, to store large amounts of textual and graphic information in the compressed form on a magnetic media, to form a report about fulfilled user work, to output different textual and graphic data being received during CAD process into a file, to a screen, printer or optional devise, and so on. As was mentioned above the main part of the SB is the graphic user interaction.

Conclusion.

It has been shown the opportunity of creating highpeformance CDS CAD system, which may be mainly applicable during the design of satellite communication, control and navigation systems. The main principles of CDS CAD were illustrated, such as the effective mathematical tools, the software structure openning, the graphic user interaction and the powerful service. There were described and analyzed such kinds of CDS CAD support, as the mathematical support basing on the algebraic coding theory, the information support (input and output data), the hardware consisting of professional PC with standard configuration and the software. During the discussion the possible variant of CDS CAD structure was presented.

Acknowledgments

The author would like to thank Dr. V. Michailov for his valuable discussions in the course of this study.

References.

1. Alekseev, A. and others. (1969).
Theory and application of pseudo random signals.
Moscow, Nauka.

2. Michailov, V. (1978).
About M-sequence assembly selection for multiplex radiosystems by cross-correlation function.
Sientific papers of MAI.
No.444, 4-12.

3. Michailov V. (1984).
About the count of maximal values of M-sequence cross-correlation function.
Moscow, Radiotechnika i electronika.
Vol.29, No.9, 1837-1840.

4. Mutter V. (1990).
The basics of noise-immunity information transmition.
Leningrad, Energoatomizdat.

5. Berlecamp E. (1971).
Algebraic coding theory.
Moscow, Mir.

6. CAD development (1989).
Moscow, Visshay shcola.