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An Interactive Layout Editor/compactor

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Rapport van het afstudeerwerk
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in opdracht van prof. dr. ing. J.Jess,
onder leiding van ir. M.van der Woude.

Table of contents

Summary.

This report describes a program made by T.G.M.van Ooijen, student for masters degree at the Eindhoven University of Technology. The purpose of the program is threefold:
The first part of the program is a symbolic layout editor: An interactive program with wich a user can build a circuit, consisting of sticks (symbolic elements) on a grafics terminal.
The second part checks the circuit to see if there are violations against design rules, rules concerning minimum distances, minimum linewidth's etc.
The last part is the start of a compaction program, a program that will shift all elements together as far as possible, without violating the design rules.

Chapter 1 : Introduction.

The department of Electrical Engineering of the Eindhoven University of Technology is planning an IC-production unit. For this unit, wich will be become operational in 1983, IC's have to be designed at the same university. In the section ES, a group of students developed, in co-operation with professor J.Jess and ir. M.van der Woude, a layout system to help future designers. On the computer of the section ES, a PDP 11/60 an interactive Fortran program was set up for this purpose. We wanted this program to take over the drawing of the geometrical layout from the designer, so he can concentrate himself on the electronic design, and on the relative placement of the elements (the topology of the layout).
One of the demands for an integrated circuit is that its surface stays as small as possible. Because the designer from now on only choses a good topology for the elements, the program has to perform a "compaction" on the layout.
A few features such a program should contain are stated below:

- -Symbolic input: A line or transistor is placed as a symbol in the layout.
- -Input via a graphics terminal.
- -Hierarchical structure: It should be possible to define a macro, wich is a layout consisting of a number of sticks and/or other macro's, and later use this macro as one of the simple elements like a line.
- -Hierarchical database: The database should have the same hierarchy, the contents of a macro appears only once, and each other time the macro is used, only a pointer to the macro should be added in the database.
- -The program has to be able to check whether the design rules (minimal distances, minimal linewidth's etc.) have been violated.
- -The symbolic has to be translated to a geometrical layout.
- -The program has to perform a compaction on the layout, if desired by the user.
- -It has to be possible that a designer draws part of the layout in the geometrical way.

During the period I stayed in section ES , I worked on three programs: A symbolic layout editor, a design rule checker and a compactor. Realized are the first version of the layout editor (wich cannot handle hierarchical structures), and the design rule checker, while the work on the compactor has been taken over by X.Timmermans.
An improved version of the layout editor was made by K.Delhij [5]. Major improvements are the hierarchical structure, and a better database.
The functions the editor is able to perform are:

- Adding elements.
- Deleting elements.
- Drawing elements.
- Printing the array wich contains the information about the elements.
- Retrieve the situation as it was before the last command.

For further information, see chapter 3, The Layout Editor. Information about the symbolic elements itself can be found in chapter 2: Sticks.
The design rule checker and compactor are described in chapter 5 and 6: Design Rule Checking and Compactor.
In short, the design rule checker is able to detect the following errors:

- Not allowed overlap of elements.
- Distances between elements that are smaller than the minimal distances.
- Not closed lines (lines with dead ends).
- Not connected transistors or contacts.
- Double placed elements (elements of the same type, that completely overlap each other).

Other design rules are enforced by the translation of symbolic to geometric layout: Lines automatically get their minimum width when translated (when the user did not specify a special width, otherwise the width is greater).
So far for this short overvieuw of my work. I like to thank everyone who helped with advises, specially my coaches professor J.Jess and ir. M.van der Woude, and also mr. H.O.Koopmans for his help concerning the computer.

Before going into the details of the design process, we should take a close look at the elements, called "sticks", our symbolic layout consists of.
As there are, in NMOS, three layers for interconnecting elements (diffusion-, polysilicon- and metallayer), we also have three different symbols in the symbolic layout for these connections, each of them symbolizing one of the aforementioned layers.
These three symbols are straight lines with a different dashing. A fourth line type is used only in the symbolic layout, having no meaning in the geometric layout: The RUNX-line. This line (name from [3]) can't be used for connections, but only for boxes around groups of elements, and to write comment into the symbolic layout.
See figure 2 in Appendix A for these lines.
Normally a line gets a width that is equal to its minimal width (2 lambda, see below for lambda). However, it is possible for a user to specify a width wich is greater. This is explained in chapter 3, the layout editor. Also the size of transistors and contacts can be ajusted in a similar way.

Other symbols used are the contacts, also called via's. They connect the three layers of different type, and so we find three of them:

- -The polysilicon-metal contact (P-M contact, P-MCT in the menu).
- -The diffusion-metal contact (D-M contact, D-MCT in the menu).
- -The diffusion-polysilicon contact (Buried contact, BURCT in the menu).

The next group of symbols consists of transistors, both driver- and loadtransistors. In fact a drivertransistor is nothing more than a crossing of a polysilicon- and a diffusionline, but we chose to have a special symbol for it. The benefits are obvious:

- -When the user has to place a transistor by explicitly giving the command TRAN, the program will be able to find all not desired transistors that result from crossings of the two lines (diffusion and polysilicon).

-Furthermore, the transistor symbol will make the picture easy understandable for designers without experiance with the program.

The symbol of the drivertransistor consists of two rectangles, drawn over each other. They represent the two crossing lines, and are dashed in the same way as those lines. When a transistor is called "vertical", this means that the polysilicon line is vertical, and the diffusion line is horizontal. Figure 2 in appendix A shows the transistor symbols.
For a loadtransistor, a third rectangle is drawn, symbolizing the implantation area.

Another symbol that won't reappear in the geometric layout like the RUNX-line is the terminal, also called pin. When a user places a box around a group of elements, there is need for a contact to the world outside the box. Terminals are the only symbols that are allowed to be placed on the surrounding rectangle (box). Lines may end on the surrounding rectangle, but only if a terminal is placed on that end.

The last symbol is the box. A box is the surrounding rectangle of a group elements, and consists of four linepieces of type RUNX. However, it is stored in memory as one element, not as four.
The symbols used and their names are taken from "CABBAGE", [3].

Figure 1 in appendix A (page 45) shows the screen after the program is started up. On the upper right we see the menu with the commands, below it the messages and a legenda of used symbols and linetypes. Left we see the window or picture window.
The picture window has scale marks and scale numbers that indicate a grid. Sticks can be placed only on the grid. So when a user tries to place one of the sticks besides a gridpoint, the program looks for the closest gridpoint and places it there.
The width of the grid can be specified by the user (in mm.). However, the distance between two gridlines will always be one lambda, lambda being the minimal stepsize of the proces. F.i. a good value for lambda at the moment is 3 micron. By specifying all distances in lambda the inputprogram will be independent of future improvements of the proces that will force lambda down.
Note : The menucommand IMPL is not operational anymore, and won't reappear in a next version.
Figure 2 in appendix A (page 46) shows the sticks, the grid has a width of 20 mm. The following sticks appear from left to right, and from top down:
The four linetypes, metal, polysilicon, diffusion and RUNX, the vertical and horizontal drivertransistor, the

vertical and horizontal loadtransistor, the poly-metal contact, the diffusion-metal contact, the buried contact, the terminal and the box.

Chapter 3. Layout editor.

The layout editor is an interactive program, used to put the description of a circuit into the computermemory in an easy and fast way. The editor produces a disk file, in wich all information is stored. It is possible to start editing a new file, it is also possible to read in an old file from disk and then to start making changes. Files can be saved under a user specified name.

Input of elements in the computer will be done via the grafics terminal, a Tektronix T4014, equiped with a joystick. Placement of sticks will always be in the next order:

First, the menucommand is selected. The terminal shows a crosshair, steerable with the joystick. By placing the crosshair in the rectangle (see figure 1 in appendix A, page 45) with the desired command and pressing the spacebar, the command is given. After that, it depends on the type of command what further input is needed.
The menuitems can be divided into the next groups:

1. Commands that add an element. These commands are:
METAL, DIFF, POLY, RUNX, LOADH, LOADV, TRANH, TRANV, TERM, P-MCT, D-MCT, BURCT and BOX. After this type of command, the user should supply one or more points in the picture window.

2. Command to delete elements. Following this command (DELT), the user should indicate an element on the screen with the crosshair.

3. Digits 0 to 9. Only used after menucommands of type 1 (adding an element), with one exception: After the DRAW-command the program needs to know whether output should go to the Tektronix terminal or to the Calcom plotter. This is indicated with the figures 1 or 2 respectively.

4. Other commands: UNDO, PRNT, DRAW, STOP. UNDO "undoes" the last command if this command was of type 1 or 2 : Adding or deleting an element.

PRNT clears the screen and prints the contents of array LIST (see chapter 4, datastructure).
DRAW clears the screen and makes a new drawing.
STOP terminates the input session.

Group number 1: Adding an element.
The elements can be divided in three groups: Line elements, point elements and BOX.

1a. Adding line elements.
Placing such an element is done by steering the crosshair into the rectangle with the command (METAL, DIFF, POLY, RUNX) and pressing the spacebar. After the command, the user can either place the crosshair in the column with digits to indicate that the line should get a special, non-default width, or directly chose the place in the window where the line should start.
Supplying the program with a point outside the menu and outside the window will give rise to an error message (OUTSIDE MENU or OUTSIDE WINDOW).
For a line that consists of only one linepiece, two points in the window should be indicated. It is also possible to indicate more than two points: For each extra point a linepiece is drawn (and written to array LIST) between the two last points. In this way a line in the form of a staircase can be drawn very fast. When more lines of the same type have to be drawn, the user can do so without going back to the menu each time. Only the last point of the first line should be indicated using the c-key instead of the spacebar. The following point (via the spacebar again) will be the starting point of the second line, and so on. Figure 3 in appendix A (page 47) shows a drawing for wich only once a command (METAL) was given.
If the user wants the width of a line to change, he has to give the command again.
Every linepiece has to be horizontal or vertical. Otherwise an errormessage is displayed (LINE NOT ORTHO). If so, the user can try to place the last point again, or chose a new command.

1b. Adding point elements.
This group consists of transistors (both driver- and loadtransistors), the contacts and the terminal. After giving the command for one of these elements (and eventually a figure), only one point on the screen should be indicated. But also in this case it is allowed to indicate more points: Then more elements will be drawn at each indicated point.

1c. Adding an element of type BOX.
The first point indicated in the window will be the anchor point of the box. Two more points need to be indicated, they are the two diagonal points of the box. The user may select the points left-under plus top-right, or right-under and top-left.

2. Deleting elements.
To delete an element, it has to be indicated with the crosshair after the menucommand DELT is given. Point elements are indicated by placing the crosshair in the middle of the symbol, line elements by placing the crosshair in the little circle in the middle of it. When the indicated point is more than half a grid unit away from the nearest anchor point, the program displays the error message "ITEM NOT FOUND".
After a succesfull deletion, the message "DRAWING NOT CORRECT" is shown. Because the terminal is not able to wipe out one element, the deleted elements stay visible. To make a correct drawing the command DRAW has to be given (followed by figure 1 wich directs the drawing to the T4014).

3. Digits 0 to 9.
As stated before, these digits are used to give lines, transistors and contacts other sizes than their default ones. For lines and contacts one digit can be supplied, for transistors (both driver- and loadtransistors) two digits are allowed, denoting the width of its polysilicon and diffusion line, and hence the length and width of its channel.
After the DRAW command, the user has to give the figure 1 or 2, depending on where the new drawing should be made, on the Tektronix or on the Calcom plotter.

4a. UNDO.
The UNDO command can be given directly after one of the commands of type 1 or 2. The situation that existed before that command will be retrieved. The effect of UNDO is also that an element will be added or deleted. Therefore, the command UNDO itself can be "undone". The effect of twice a command UNDO is nil.
When an UNDO command is given after a type 3 or type 4 command (except for UNDO itself), an error message (WRONG USAGE UNDO) is displayed.

4b. PRNT.
PRNT gives the user the opportunity to inspect the

array in wich all elements are placed. This can be, for instance, for the next reason:
The user wants to know the width's of the lines on the screen. These width's are not visible in the symbolic layout. The PRNT command clears the screen and then prints the array LIST (see chapter 4, datastructure).
For each element one line is printed, starting with the address of the first integer of the element (the first integer of the first element has address 1, the first integer of the second element has address 9 and so on).

4c. DRAW.

When the drawing is not correct anymore, a new one can be made using the DRAW command. The program asks whether the drawing should be directed to the Tektronix terminal or to the Calcom plotter with the message : "T4014/CAL563 ? 1/2". The user has to answer with the figure 1 or 2 in the menu (not by pressing the key 1 or 2).

4d. STOP.

Command STOP terminates the input session. The program now asks the user whether the contents of the array should be saved, and if so, under wich filename. The next question will be whether the user wants to go on editing a new file or wants to stop the program.

Chapter 4. Datastructure.

Datastructure of the program.
The elements will be placed in a linear array, called LIST. The length of the array is 1600 integers and for each element LIST contains eight integers, so 200 elements can be placed.
When 200 elements shouldn't be enough, the maximum number of elements can be increased simply by adjusting the length of array LIST.

The information concerning one element consists of eigth integers:

1 : Type of the element. This is an integer in the range from 1 until 17, its meaning is :

1 . Vertical line of type metal.
2 . Vertical line of type diffusion.
3 . Vertical line of type polysilicon.
4 . Vertical line of type runx.
5 . D-M contact.
6 . P-M contact.
7 . Buried contact.
8 . Terminal element.
9 . Vertical drivertransistor.
10. Horizontal drivertransistor.
11. Vertical loadtransistor.
12. Horizontal loadtransistor.
13. Horizontal line of type metal.
14. Horizontal line of type diffusion.
15. Horizontal line of type polysilicon.
16. Horizontal line of type runx.
17. Surrounding rectangle (box).

2 : Orientation of the element.
When placed the orientation of the elements always will be 1.

3,4 : Co-ordinates of the anchorpoint of the element. For a point element (transistor, contact, terminal) the anchorpoint is in the middle of the symbol, for a line element the anchorpoint is in the middle for a linepiece with a length of an uneven times lambda, and in the middle plus or minus half lambda for a linepiece with a length of an even times lambda.

5,6 : Co-ordinates of the left-under point of the surrounding rectangle of the geometrical representation of the element.

7,8 : Co-ordinates of the right-upper point of the surrounding rectangle of the geometrical representation of the element.

The elements will be placed sorted, in order of increasing X co-ordinate of the anchorpoint, and, when more elements share the same X co-ordinate, in order of increasing Y co-ordinate.
From the sorting of the elements it follows that part of the contents of array LIST has to be shifted when elements have to be inserted. To find out whether this shifting is not slowing down the interactive editing proces, a testprogram was written to check this. With this testprogram it was possible to shift 7400 integers per second, that is about 460 elements in 0.5 second (half a second is taken as the maximum average delay time). Because the average number to be shifted is half of the number of the elements that are present, there shouldn't be more than 920 elements in the array. With 200 elements we are on the fair side (average delay time about 0.1 second).

All information is kept in main memory as long as the user goes on with his input session. When he stops doing so, the program asks if the contents of the array should be saved, and if so, under wich filename. The file that is made by the program gets the following attributes :

NAME	= Name as supplied by the user.
TYPE	= UNKNOWN.
FORM	= FORMATTED.
ACCESS	= DIRECT.
RECORD SIZE	= 4.
ASSOCIATE VARIABLE	= NFOP.

Disk files are in readable format and can be displayed on the screen via the PIP program.
Throughout the program a few pointers are used. The most important ones are IEND and IPTR.
IEND points always to the last integer of the last element in array LIST (IEND = 16 when two elements reside in LIST).
IPTR points to the last integer of an element in array LIST.

Chapter 5. Design rule checking.

There are two kinds of design rules : Design rules wich are implicitly obeyed and design rules the program has to check the circuit on. To the first group belong rules dealing with minimal linewidth's and minimal overlap of the lines of a transistor. When the symbolic layout is translated to a geometrical layout, an element, f.i. a line, automatically changes to a geometrical line of minimum width. That means that the program doesn't have to check this width anymore.
The second group of design rules are the rules the program has to check.
The next errors will then be found :

- Distances between elements that are smaller than the minimal distance, f.i. between two lines.
- Not allowed overlap of elements, f.i. a transistor and a contact.
- Not closed lines (lines with a dead end).
- Not connected transistors or contacts or terminals.
- Double placed elements (elements of the same type that completely overlap each other).

There are also errors that won't be detected :

- Lines that are longer than a maximum length.
- Parasitic capacitances.

The design rule check is performed after the edit session is terminated. It would be better for the designer, if each element he draws during his editing would be checked against all other elements that are present at the moment. There are two reasons why we still chose to perform the check afterwards :
The first reason is the fact that there are a few cases two elements are allowed to overlap only if a third element is placed on the crossing (examples are a crossing of a diffusion and a polysilicon line, on wich a buried contact has to be placed, and a crossing of a RUNX-line with a line of one of the other three types, on wich a terminal should be placed). At the moment the crossing is established it is impossible for the program to know if this third element indeed will be placed.

The second reason is that for design rule checking each element has to be checked against each other element. In the compactor the program is going to perform exactly the same check, to see if they are connected. By placing the design rule checker in the compactor, this proces (order N**2) is executed only once, wich saves computer time.
The design rules specifying the minimal distances are taken from Mead and Conway [1].

Chapter 6. Compaction.

When we would translate a symbolic layout to a geometrical layout, the latter would be rather "loose". To shift the elements together is the pupose of the compaction program.
There are a few methods by wich such a compactor could work :

- Compression Ridge Method [7].
  This method removes bands of continuous area. Drawback : This is a trial and error method, because the optimal place for compression ridges is unknown.

- Localized Placement Method.
  This method (used in "STICKS", [6]) places successive elements on basis of connectivity. If parrallel path's exist in the graph, this method has a low efficiency.

- Critical Path Method.
  This method is used in programs like "FLOSS" [8] and "CABBAGE" [3].

We chose for the critical path method. In the first fase of the compaction program, the elements are divided into groups :
Two elements are placed in the same group if they are connected in the direction perpendicular on the compaction direction (connection direction is the direction of the line element involved).
Groups will be shifted as a whole. The line elements in the direction of compaction will be regarded as elastic connections. They are not placed in any group, and their length is calculated after the compaction from the co-ordinates of the elements they connect.
The dividing into groups serves two goals :

- The problem gets a lower complexity.
- It prevends connected elements to float away from each other.

We can map the groups on a graph : The groups itself form the nodes of the graph, while the distances between them form the branches. At each branch both the minimal and the actual distance can be written.
There exist two of these graphs : One for compaction in horizontal direction and one for compaction in vert-

ical direction.
Once the graph is known, the critical path can be calculated. Now all groups residing on the critical path get their new location, based on the minimum distance to their predecessor. The other groups shift along with the first groups, but afterwards they will still have a certain amount of "freedom" in their placement.
There is still a lot of work to be done before the compaction program will function as described. The following pieces of the program are realized : A datastructure is set up for dividing the elements in groups, and for setting up the graph.
For the division of the elements, a program is written that will make a list with all connections a certain element has with other elements.

Chapter 7. Conclusions.

An interactive layout editor has been made. It can be improved in the following ways :

- By making it possible to define macro's, and in that way introducing hierarchy into the program.
- By making it possible to indicate a line (f.i. when deleting it) on every point of its length, not only on its anchorpoint.
- By making it possible to define a linepiece on the border of the box to be a terminal, instead of just one point.

The first two problems are already solved by K.Delhij [5]. The last one remains for the future.
Although the editor isn't perfect yet, it is possible to enter a symbolic circuit into the computer in a simple and fast way.
The second program, the design rule checker, has been implemented, and initial tests show good result : It detects violations of the most common design rules. However it could be improved by extending it in a way it can calculate lineresistances and -capacitances.
The compactor hasn't been finished yet. One of the major problems we can see at this moment is the appearance of maximum constraints in the graph : Two groups that have a minimum distance to each other and a maxiumum distance to each other as well.

Chapter 8 : Description of program and subroutines.

Subroutines of the layout editor are :

Subroutine ADDAR(IEND).

IEND is a pointer to the last, filled place in array LIST.

ADDAR adds one element to array LIST. The elements are placed in order of increasing x-coördinate of the anchor, and when more elements share the same x co-ordinate, in order of increasing y co-ordinate. From this it follows that before an element can be inserted, part of the array LIST has to be shifted. In chapter .... it is shown by a test program, that moving a part of the array is not significantly slowing down the program, when the amount of eleménts stays under 200.
Subroutine ADDAR checks the number of placed elements and displays an error message in case this number exceeds 200.

Subroutine DELAR(IEND,ITEM,LETTER).

IEND is a pointer to the last filled place in array LIST.

ITEM is the number of a menu command. (When a user first selects DEL (DELete uses subroutine DELAR) in the menu, but then changes his mind and selects a new menu command instead of indicating an anchor, the command has to be passed on to subroutine OOYEN5)

LETTER contains a number indicating wich key was used in subroutine DELAR to indicate the anchor (see routine CURDEF in the GINO-manual [2]).

This subroutine deletes one element from array LIST. The contents of the array following the deleted element are shifted upward to fill the open space.
In the case the subroutine is not able to find the element pointed to, or when the array is empty, the error message "ITEM NOT FOUND" is displayed.

Subroutine PRAR(IEND).

IEND is a pointer to the last filled place in array LIST.

Subroutine PRAR erases the screen and then prints the contents of array LIST. For each element one line appears on the screen, each line giving the eight integers of an element , preceeded by a pointer telling the address of the first integer of the element.

Subroutine GETMEN(X,Y,ITEM,NOT).

X and Y are coördinates on the screen, read in by the GINO-routine CURSOR.

ITEM is the number of a menu command (see DELAR).

NOT indicates whether the point with co-ordinates (X,Y) lies within the menu (NOT = 0) or outside the menu (NOT = 1).

Input for subroutine GETMEN are the coördinates of a point. Output are ITEM and NOT. NOT = 1 indicates the point was not within the boundaries of the menu. When the point was inside the menu, the value of ITEM will be a number in the range 1 - 40 denoting wich command was selected.

Subroutine LINE(IEND,ITEM,LETTER).

IEND is a pointer to the last, filled place in array LIST.

ITEM is the number of a menu command (see subroutine DELAR).

LETTER is a figure indicating wich key was used in subroutine LINE to indicate the last point of the line.

Subroutine LINE asks for co-ordinates of points inside the picture window (via GINO-subroutine CURSOR), draws a line between them, and stores the line element in array LIST.
Error messages are given if the points do not indicate an orthogonal line or if one of the points lies outside the rectangle (except if it were a new menu command). The anchor point of a line will be drawn in the middle as a little circle. At last, LINE calls subroutine ADDAR to store the element in array LIST.

Subroutine ERROR(NUMBER).

NUMBER is the number of the indication. If Number is in the range 1 to 8 an error is indicated. If it's higher, the program asks the user for more input.

ERROR draws the users attention by lighting a point in front of one of the error messages or indications.

Subroutine BOX(IEND,ITEM,LETTER).

IEND is a pointer to the last, filled place in array LIST.

ITEM is the number of a menu command (see subroutine DELAR).

LETTER is a number indicating wich key was used in subroutine BOX to enter points (see GINO-manual [2], subroutine CURSOR).

Subroutine BOX asks for two points on the screen. The points are two diagonal points of the surrounding rectangle. The surrounding rectangle is drawn, and stored in array LIST.

Subroutine CNTACT(IEND,ITEM,LETTER).

IEND is a pointer to the last, filled place in array LIST.

ITEM is the number of a menu command (see subroutine DELAR).

LETTER is a figure indicating wich key was used in subroutine CNTACT to enter points (see GINO-manual [2], subroutine CURSOR).

CNTACT asks for one point on the screen and then draws the symbol of a contact or a pin, at the indicated place. Depending on the type of the contact or pin, a different symbol is drawn (see legenda underneath the menu). Appendix A contains a few drawings where contacts and other symbols appear.

Subroutine TRAN(IEND,ITEM,LETTER,LOAD).

IEND is a pointer to the last, filled place in array LIST.

ITEM is the number of a menu command (see subroutine DELAR).

LETTER is a figure indicating wich key was used in subroutine TRAN to enter a point.

LOAD is a flag telling the transistor is of the driver type (LOAD = 0) or of the load type (LOAD = 1).

After asking the co-ordinates of a point inside the rectangle where the transistor has to be placed, its symbol is drawn (symbol of horizontal transistor if command was TRANH, symbol of vertical transistor if command was TRANV) and the element is stored in array LIST.

Subroutine DRAW(IEND).

IEND is a pointer to the last filled place in array LIST.

DRAW wil draw all elements present in array LIST. When symbols have been deleted, they remain visible on the screen. On the user command DRAW the screen will be erased and a new picture drawn.

Subroutine UNDO(IEND).

IEND is a pointer to the last filled place in array LIST.

This subroutine restores the situation as it was before the last given command, if this command was of the type "adding or deleting an element" (METAL, DIFF, POLY, IMPL, TRANV, TRANH, LOADV, LOADH, BOX, D-MCT, P-MCT, BURCT, RUNX, TERM and DELT). An error message is displayed in the case the last command cannot be "undone" anymore.

Subroutine MENUFRAME.

MENUFRAME erases the screen, draws the menu and writes the error messages underneath it. Furthermore a legenda is drawn of linepieces and symbols.

Subroutine MENUFI(IR,IK,IHOL).

IR is a rownumber in the menu.

IK is a columnnumber in the menu.

IHOL is a Hollerith string, containing the string to be placed in the menu.

MENUFI fills a place in the menu, indicated by the row- and columnnumber, with the string in IHOL.

Subroutine MENU1.

MENU1 draws the complete menu by first calling MENU-FRAME and then calling MENUFI as many times as there are menuitems. Characterstrings handed over to MENUFI are of the format:

    6HTEXT*.

As shown, the string to be written in the menu, "TEXT", has to be succeeded by *. and preceeded by H and the number of letters plus 2 (for the *.).

Subroutine ROOST(CALCOM).

CALCOM is a flag indicating whether drawing should be done on the Tektronix tube (CALCOM = 0) or on the Cal-comp plotter (CALCOM = 1).

This subroutine draws the window on the screen, includ-ing scale marks and scale numbers. If CALCOM = 1 no scale numbers are drawn.

Subroutine OOYEN5(NEW).

NEW is a flag indicating whether or not it is the first time this subroutine is called. Except for the first time (initialization in subprogram BLOCK DATA), array LIST has to be initialized again (every element of LIST becomes zero).

This subroutine deals with all input via the menu. First it calls GINO-routines like CURDEF, T4014 etc. to initialize GINO-commons, and the Tektronix terminal. Then some variables of the program itself get their in-itial value. To do the same with the scaling factors IX1 and IY1, the user is asked for the width of the grid of the window IWIDTH.
Now the menu and the window are drawn and the user can give his first menu command. Each command is checked and if found valid, the program calls the corresponding subroutine.
To depart from OOYEN5, the menu command STOP should be used.

Subroutine TITLE(NAME,UNITNR).

NAME is the name of the file to be opened.

UNITNR is the logical unit number of the file.

TITLE opens a diskfile, wich will have the following attributes:

```
UNIT = UNITNR
NAME = NAME
TYPE = UNKNOWN
FORM = FORMATTED
ACCESS = DIRECT
RECORDSIZE = 4
ASSOCIATE VARIABLE = NFOP
```

Subprogram BLOCK DATA.

This subprogram, consisting of a group of non-executable statements, defines and initializes variables and constants. In BLOCK DATA one blank common block appears and the named common blocks MENUCM, DRAWCM and UNDOCM.
The following arrays and variables are placed in common blocks:

Blank common block.

IREC(8) : Array containing eight integers, used as a temporary storage for one element.
LIST(1600) : Main array, containing the information about all elements that are present at the moment. LIST is initialized to zero at the start of the program.
IWIDTH : Width of one grid unit (in mm.) of the window.
X1, X2, Y1, Y2 : Boundaries of the window. Present values are 10, 298, 10 and 270 respectively.
LREC, NREC : Length of the datablock of one element and the maximum number of elements, present values 8 and 200.

COMMON/DRAWCM.
IX1, IY1 : Scaling constants used when drawing symbols on the screen.

COMMON/MENUCM.
XML, YML, XMR, YMR : Boundaries of the menu. Their present value is 300, 130, 368, 270.
IROWS, ICOLS : Number of rows and columns in

the menu, initial values 10 and 4.

COMMON/UNDOCM
IUNDO : The current command is "undoable" if IUNDO is 2 or 3.

Subroutine INIT(NUMBER).

NUMBER is a digit telling INIT wich initialization routines should be called.

Subroutine INIT initializes GINO-commons and devices. For instance, when the Tektronix terminal will be used, INIT calls the (GINO) subroutines T4014, DEVSPE and WINDOW (see GINO-manual [2] for the meaning of these routines).

Program OOYEN4.

This is the main program. In this part the user is asked if he desires to open an existing file, or wants to start editing a new file. When the editing is done the program asks if the contents of LIST should be saved in a disk file, and if the user wants to go on using the program, start editing a new or existing file again. After these questions subroutine OOYEN5 is called wich takes over all user-program interaction.

Subroutines of the design rule checker/compactor are :

Subroutine ADDGRP.

This subroutine adds the element pointed to by ITMPTR to the group pointed to by GRPPTR. The number of elements in the group is incremented by 1, and a pointer to the element is added in the group. Finally the surrounding rectangle of the group is adapted if the element or a part of the element falls outside the existing surrounding rectangle of the group.

Subroutine NEWGRP.

NEWGRP creates a new group. The list of items is checked for an element not yet placed in a group (the element may not be a line in the direction of compaction). If there is such an element, its surrounding rectangle is copied into the surrounding rectangle of the group. The number of elements in the group is set to 1, a pointer to the element is added and the list of groupindexes is extended with a pointer to the new group.

Logical function OVRLAP(ITMPT1,ITMPT2,LAMBDA).

ITMPT1 and ITMPT2 are pointers to elements in the element list.

LAMBDA is a flag.

Function OVRLAP checks if the elements pointed to by ITMPT1 and ITMPT2 overlap each other. When the flag LAMBDA is set to 0 OVRLAP becomes true only when the elements actually overlap each other. If LAMBDA is set to 1 OVRLAP becomes true when the elements overlap each other, or when they have a mutual distance less than NLAMBD.

Logical function CONNEC(ITMPT1,ITMPT2).

ITMPT1 and ITMPT2 are pointers to elements in the element list.

This function checks if the elements pointed to by ITMPT1 and ITMPT2, wich overlap each other, are allowed to be connected. One of the elements always is a line, while the other isn't.
The information concerning these connections is placed in an array of size (8,10). The subscribt variables are calculated from the type numbers of the two elements.

Logical function DISTAN(ITMPT1,ITMPT2).

ITMPT1 and ITMPT2 are pointers to elements in the element list.

DISTAN is made true when the distance between the elements (calculated in the function IDIST) is greater than the minimal distance following from the design rules. The design rules specifying the minimal distances are taken from Mead and Conway [1].
They are placed in a linear array, because placing them in a square array would mean all figures appear twice. However, this implicates that the index has to be calculated in the subroutine.

Function IDIST(ITMPT1,ITMPT2).

ITMPT1 and ITMPT2 are pointers to elements in the element list.

This function calculates the distance between elements pointed to by ITMPT1 and ITMPT2. When the elements have a piece of the X-axis or Y-axis in common, the value of IDIST will be the real distance between them. If not so, IDIST is calculated by taking the root of the sum of squares of the distances in X- and Y-direction, and truncating the result.

Subroutine NXTITM(FLAG).

FLAG is a flag indicating whether pointer ITMPTR (FLAG=0) or pointer GRITPT (FLAG=1) will be altered.

Depending on the type of the element pointed to, the pointer is incremented by 8 (line element), by 6 (point element), or , in the case of a compound element by 7 plus the number of terminals times 5 (length of terminal information).

Function NXTGRP.

NXTGRP updates the grouppointer. The value of NXTGRP will be GRPPTR plus 5 plus the number of elements in the group.

Subroutine NXTCON(CONPT1).

CONPT1 is the pointer to be updated.

NXTCON updates the connection pointer. The value of CONPT1 will be its old value plus 1 plus the number of connections.

Subroutine CNECT.

This subroutine checks all pairs of elements if they are overlapping, then, if they overlap, CNECT calls subroutine DRCHCK to see if this overlapping is allowed. If not, an error message is displayed. In the case it was allowed, one of the elements is a line and subroutine LINCLO will be called to fill in the pointer(s) to the elements that close the line.

Subroutine GROUP.

Subroutine GROUP places the elements in groups. Linepieces in the direction of compaction are not included in the groups.

Logical function COVER(ITMPT1,ITMPT2).

ITMPT1 and ITMPT2 are pointers to elements in the element list.

This function checks if two elements, pointed to by ITMPT1 and ITMPT 2 completely cover each other. If they do COVER becomes true.

Subroutine LINCLO(JFLAG).

JFLAG equal 1 means ITMPTR points to line element and GRITPT points to a non-line element, JFLAG equal 2 means ITMPTR points to a non-line element and GRITPT points to a line element, while JFLAG equal 3 means that both ITMPTR and GRITPT point to line elements.

Subroutine LINCLO fills in the addresses of the elements that close a line. Each datablock of a line element contains two pointers to its closing elements. Both pointers are zero when the program is started up. Subroutine CNECT calls LINCLO when it finds a pair of overlapping elements of wich at least one is a line.

Subroutine DRCHCK(ITMPT1,ITMPT2,NOT,I1,J1,TRMPTR).

ITMPT1 and ITMPT2 are pointers to elements in the element list.

NOT is a flag : NOT = 1 means one of the design rules has been violated.

I1 and J1 are equal to J and K in (the calling) subroutine CNECT.

TRMPTR is a pointer to a terminal of a compound.

Subroutine DRCHCK is the design rule checker. It checks whether the elements pointed to by ITMPT1 and ITMPT2, wich overlap each other (with LAMBDA = 1, so there doesn't have to be a real overlap), are allowed to be connected, or if they are at a distance greater than their minimal distance. In the case one of the elements (or both) is a line, subroutine CHKTYP is called wich takes over the check. In all other cases DRCHCK performs the check itself.

Subroutine CHKLIN.

This subroutine checks if all lines have been terminated properly. If one of the two pointers to the closing elements of one of the line elements is zero, an error message is displayed on the screen.

Subroutine CHKTYP(ITMPT1,ITMPT2,NOT,I1,J1,TERMPT).

ITMPT1 and ITMPT2 are pointers to elements in the element list.

NOT is a flag : NOT = 1 means one of the design rules has been violated.

I1 and J1 are equal to J and K in subroutine CNECT.

TERMPT is a pointer to a terminal of a compound, and equal to TRMPTR in DRCHCK.

Subroutine SAVE(ITMPT1,ITMPT2).

ITMPT1 and ITMPT2 are pointers to elements in the element list.

Subroutine SAVE saves the addresses of the two elements wich overlap each other (LAMBDA = 0, so real overlap), when this is allowed only when a third element is placed on the crossing. This routine is called in the case a polysilicon line and a diffusion line cross (a buried contact should be placed on the crossing) or in case a polysilicon line, a diffusion line or a metal line crosses a RUNX line (a terminal should be placed on the crossing).

Program COMPAC.

This is the main program of the design rule checker/compactor. It initializes the variables used in the subroutines and fills the memory with information to test the design rule checker.
Afterwards, it writes the contents of the memory (array MEM) to the screen, so the user can see wich errors were detected by the program.

Chapter 9: Description of error messages.

Error messages are written on the screen every time the menu is drawn. A point will lit up in front of an error message whenever this error occurs. The last two messages inform the user that the program requires further input ("1" or "2" in the case the last command was a DRAW command, to inform the program whether output should be send to the T4014 or to the Calcom plotter), or that the drawing on the screen is not anymore a correct mapping of the contents of array LIST (for instance after deletion of elements).
The user can encounter the following errors:

Error 1 : OUTSIDE WINDOW

The program expected input from the window, while the user supplied a point outside it. After this error message, the user can either give a correct point or choose another menu item.

Error 2 : OUTSIDE MENU

Like error 1, except that this time the program expected input from the menu. The user must now give a menu command.

Error 3 : TOO MANY ITEMS

This error message is displayed when array LIST already contained 200 elements at the moment the user tried to store another element. This last element will not be placed in LIST. The maximum of 200 elements can be increased (at the cost of computer memory) by changing the length of array LIST to eight times the desired maximum number of elements, and then recompiling the program.

Error 4 : ARRAY EMPTY

An attempt has been made to draw the circuit while array LIST was empty. The user should first fill the array by placing elements before giving the DRAW command.

Error 5 : ITEM NOT FOUND

After the command DELT (delete), the program expects the user to point to an anchor point of one of the elements on the screen. The maximum distance between the indicated point and the anchor point is half the width of a grid unit, in order to let the program be able to locate the element. If the distance is greater this message is displayed, and the user should try again, or choose a new command.

Error 6 : COMMAND NOT OK

Some places in the menu are reserved for future extensions of the program. When a user selects one of them, or selects a figure in the menu not following one of the commands META, DIFF, POLY, RUNX, TRANV, TRANH, LOADV or LOADH, this message is displayed. The user should select an existing command, or an allowed sequence of commands.

Error 7 : LINE NOT ORTHO

Seeing this message on the screen means that the the last two points of a line do not share the same X or Y co-ordinate. This last linepiece is rejected, and the user can either supply a new point, wich has to be on a horizontal or vertical line with the second-last point, or select a new menu command.

Error 8 : WRONG USAGE UNDO

The command UNDO is allowed only if the last command added or deleted an element.

Message 9 : T4014/CAL563 ? 1/2

Informs the user that further input is required. This message appears after the DRAW command. A "1" directs the output to the T4014 and a "2" to the Calcom plotter.

Message 10 : DRAWING NOT CORRECT

After a deletion of an element this message appears. At this moment the screen contains more elements than array LIST. To get a correct drawing, the DRAW command has to be given.

Appendix A : Figures.

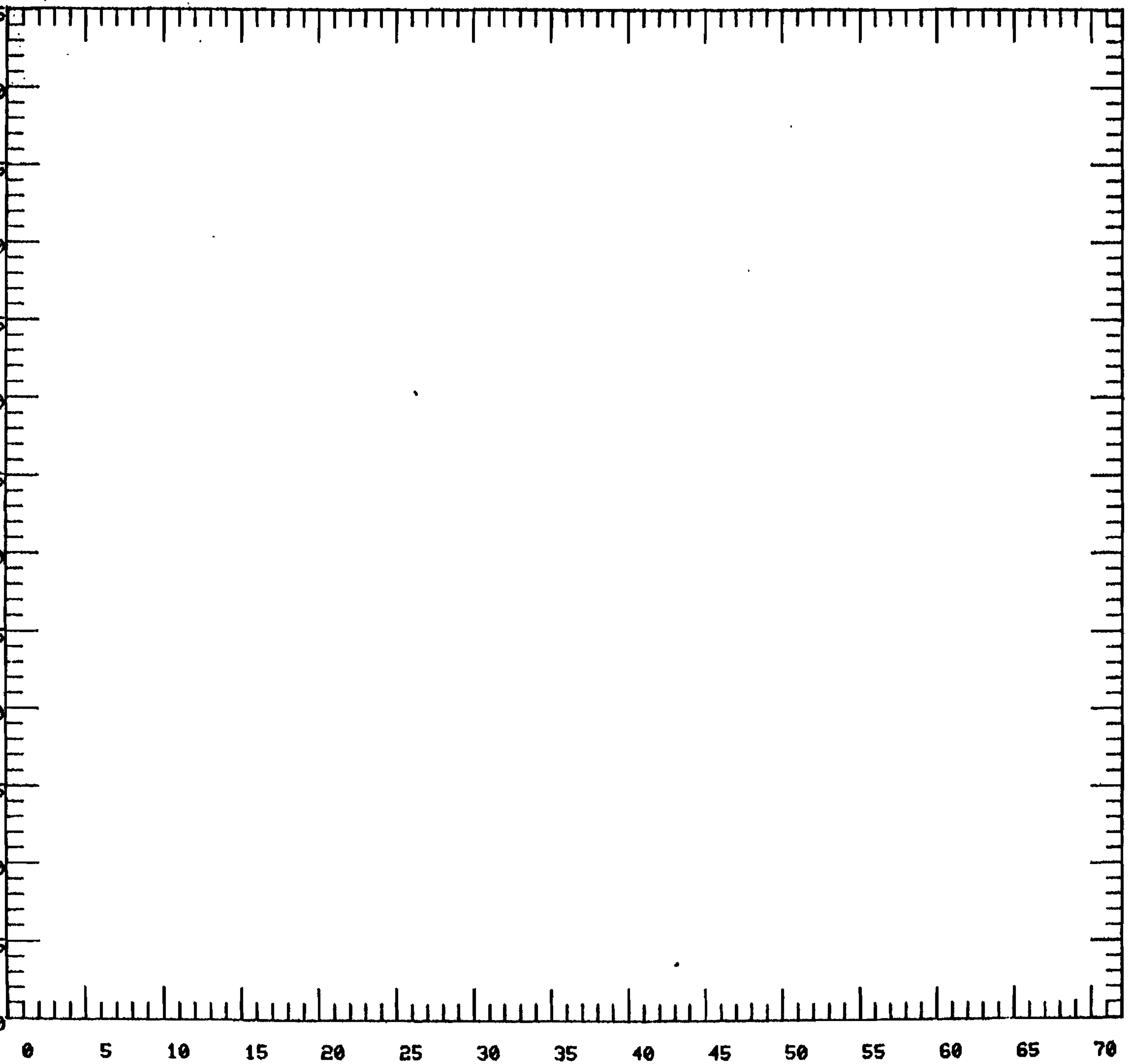
In this appendix the reader will find a few drawings. They are respectively :

Figure 1.
A drawing of the screen with the menu and an empty window, grid spacing is 4 mm.

Figure 2.
A drawing of the screen like figure 1. Grid spacing is 20 mm. and all sticks are drawn, see chapter 2 for a description.

Figure 3.
Like figure 1. Grid spacing is 8 mm. A few lines are drawn, type metal (all lines are drawn with only one menucommand).

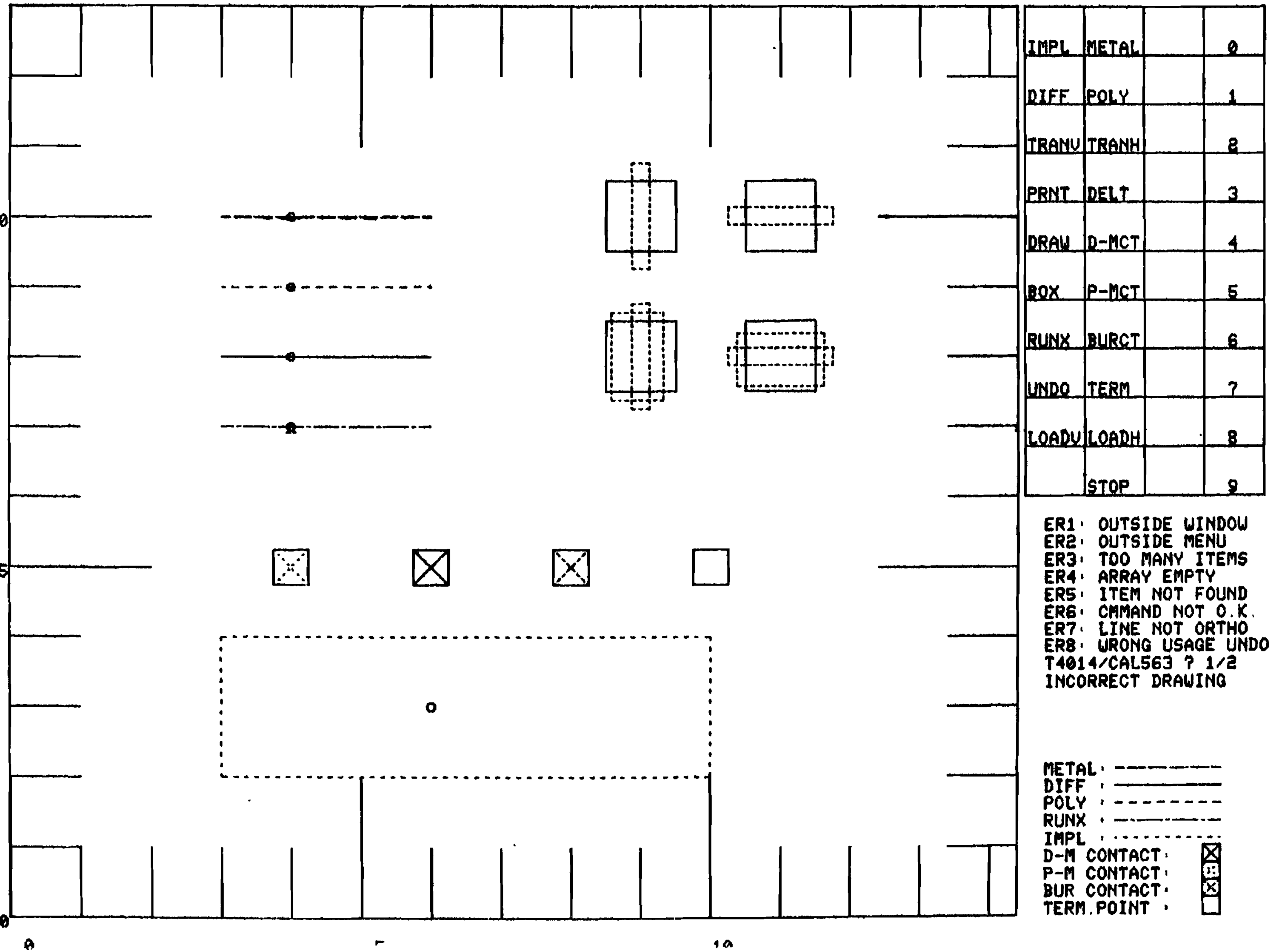
Figure 4.
A drawing of the screen with the symbolic layout of a T-flipflop.

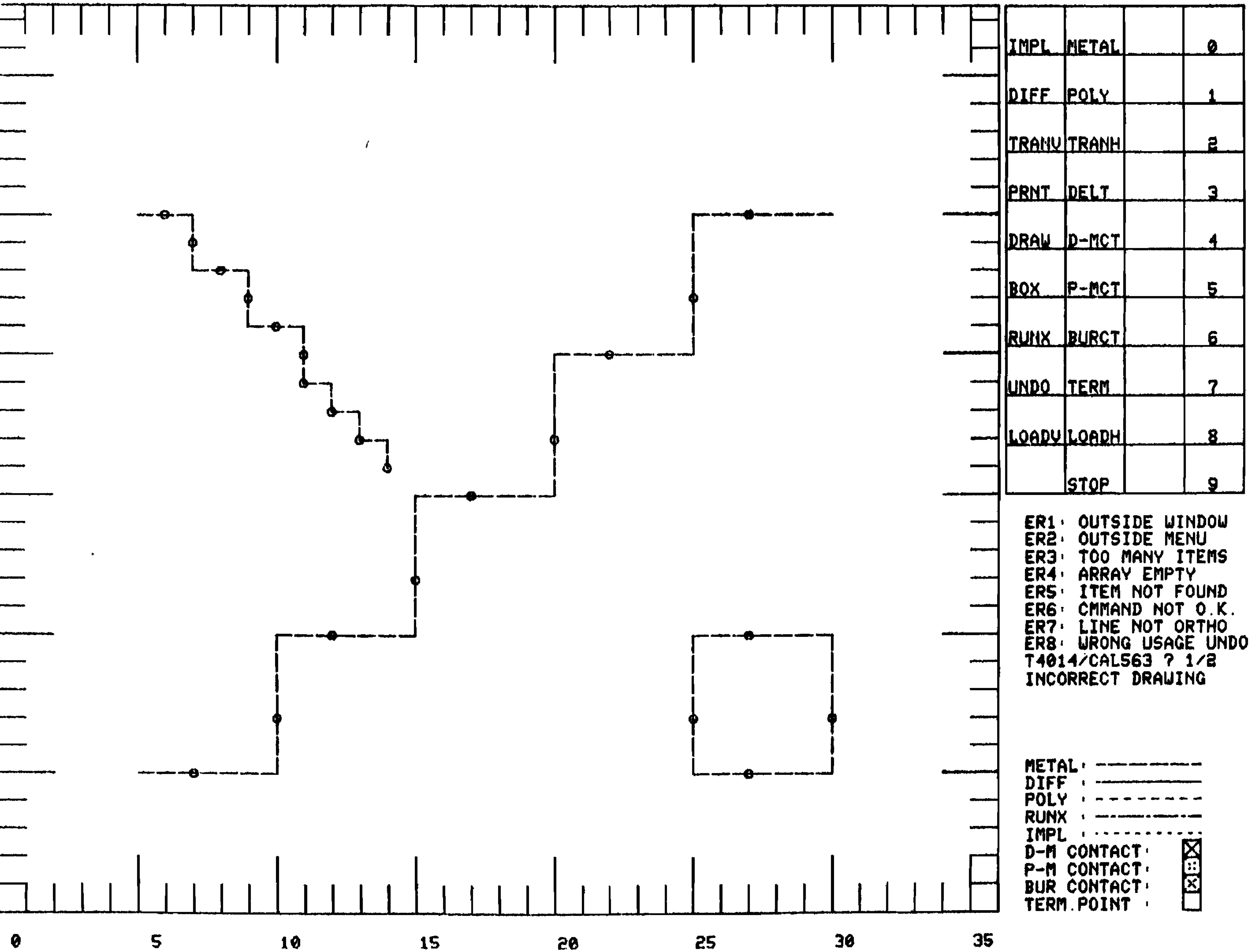


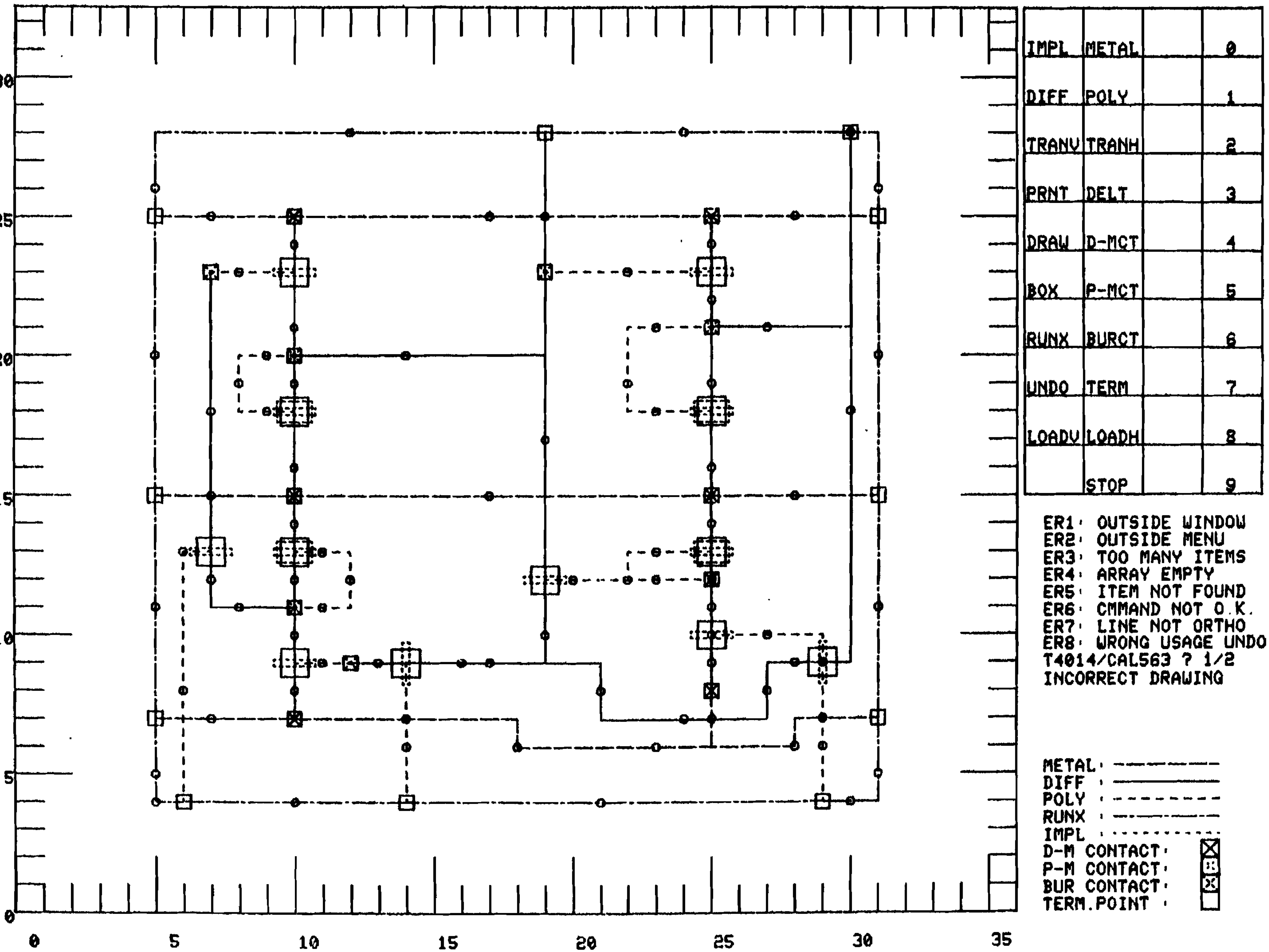
IMPL	METAL		0
DIFF	POLY		1
TRANV	TRANH		2
PRNT	DELT		3
DRAW	D-MCT		4
BOX	P-MCT		5
RUNX	BURCT		6
UNDO	TERM		7
LOADV	LOADH		8
	STOP		9

ER1: OUTSIDE WINDOW
ER2: OUTSIDE MENU
ER3: TOO MANY ITEMS
ER4: ARRAY EMPTY
ER5: ITEM NOT FOUND
ER6: CMMAND NOT O.K.
ER7: LINE NOT ORTHO
ER8: WRONG USAGE UNDO
T4014/CAL563 ? 1/2
INCORRECT DRAWING

METAL:
DIFF :
POLY :
RUNX :
IMPL :
D-M CONTACT:
P-M CONTACT:
BUR CONTACT:
TERM.POINT :


IMPL
METAL
0
DIFF
POLY
1
TRANV
TRANH
2
PRNT
DELT
3
DRAW
D-MCT
4
BOX
P-MCT
5
RUNX
BURCT
6
UNDO
TERM
7
LOADV
LOADH
8
STOP
9
ER1: OUTSIDE WINDOW
ER2: OUTSIDE MENU
ER3: TOO MANY ITEMS
ER4: ARRAY EMPTY
ER5: ITEM NOT FOUND
ER6: CMMAND NOT O.K.
ER7: LINE NOT ORTHO
ER8: WRONG USAGE UNDO
T4014/CAL563 ? 1/2
INCORRECT DRAWING
METAL:
DIFF :
POLY :
RUNX :
IMPL :
D-M CONTACT:
P-M CONTACT:
BUR CONTACT:
TERM.POINT :
0
10


IMPL METAL 0
DIFF POLY 1
TRANV TRANH 2
PRNT DELT 3
DRAW D-MCT 4
BOX P-MCT 5
RUNX BURCT 6
UNDO TERM 7
LOADV LOADH 8
STOP 9
ER1: OUTSIDE WINDOW
ER2: OUTSIDE MENU
ER3: TOO MANY ITEMS
ER4: ARRAY EMPTY
ER5: ITEM NOT FOUND
ER6: CMMAND NOT O.K.
ER7: LINE NOT ORTHO
ER8: WRONG USAGE UNDO
T4014/CAL563 ? 1/2
INCORRECT DRAWING
METAL:
DIFF :
POLY :
RUNX :
IMPL :
D-M CONTACT:
P-M CONTACT:
BUR CONTACT:
TERM.POINT :
0
5
10
15
20
25
30
35


IMPL METAL 0
DIFF POLY 1
TRANV TRANH 2
PRNT DELT 3
DRAW D-MCT 4
BOX P-MCT 5
RUNX BURCT 6
UNDO TERM 7
LOADV LOADH 8
STOP 9
ER1: OUTSIDE WINDOW
ER2: OUTSIDE MENU
ER3: TOO MANY ITEMS
ER4: ARRAY EMPTY
ER5: ITEM NOT FOUND
ER6: CMMAND NOT O.K.
ER7: LINE NOT ORTHO
ER8: WRONG USAGE UNDO
T4014/CAL563 ? 1/2
INCORRECT DRAWING
METAL:
DIFF :
POLY :
RUNX :
IMPL :
D-M CONTACT:
P-M CONTACT:
BUR CONTACT:
TERM.POINT :
0 5 10 15 20 25 30 35

Appendix B : Bibliography.

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