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Computer Program

A Fast Fourier Transform (FFT) Program for a Programmable Pocket Calculator TI 59

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Summary

This paper presents an FFT-program written for the use of the programmable pocket calculator of Texas Instruments TI 59. The program consists of the following routines: Input/output; FFT forward and inverse; shuffling and a routine that converts the FFT-coefficients in case that real numbers were put in. The maximal number of input data is 32 complex or 64 real data. Listings of all routines are given and the program handling is described. Peak sharpening and removal of background (PARG) are examples to demonstrate the handling of routines.

1. Introduction

The widespread availability of digital computers and the development of an algorithm for a Fast Fourier Transform (FFT) by *Cooley* and *Tukey* (1965) have led to the FFT becoming a very powerful tool in a large sphere of applications. Several versions of the Cooley-Tukey algorithm have been published, and reviews are given by *Bergland* (1969) and *Singleton* (1969), among others. One of the shortest FFT-subroutines written in FORTRAN known to the author was given by *Ahmed* and *Rao* (1975). The possibility of high speed convolution and correlation, of digital filtering etc. with the aid of FFT led to applications in image processing and spectroscopy, and in this article, to XRMA with an EDS.

The program described in this paper is written for a programmable pocket calculator (TI 59, Texas Instruments) and is derived from the version of *Ahmed* and *Rao*. It can be helpful for those who want to become familiar with the principle of FFT or who have no direct access to a computer but want to test the utility of FFT for a special problem (if the number of data is small enough). It can be used, for example, to test a correction procedure for a single spectral peak when programming a computer is too expensive.

2. Program structure

In all routines addressing is absolute to provide a fast execution. The memory of TI 59 is used in the following partitioning:
Memory No 000–239: Program registers 000–239
Memory No 959–240: Data registers 00-89
That means: block 2, 3 and 4 are reserved for data only. They can be read in from 3 sides of magnetic cards (or written to). The program routines are situated in block 1 and must be read in from one side of card. In this way the program can be exchanged optionally without affecting the content of data registers. This is very similar to the "common area" of FORTRAN.

A listing of 4 routines is given in Table 5.

1. Input and output of data (called "ENTER" and "BRING OUT").
   There are separate routines for real and complex numbers.
2. FFT forward and inverse (called "DFT").
3. Shuffling of FFT-coefficients (called "ARRANGE").
4. Conversion of FFT-coefficients if real numbers were entered (called "CONVERT").

DFT and CONVERT are supported by program 04 of the solid state standard software module "Master 1". The output routines are written for the use of printer PC-100 A.

3. Data capacity

The program allows to transform a number of data which is integer power of 2 (radix 2). The maximum number of data points is 32 complex or 64 real numbers. The data are stored in registers starting at No 20. After DFT the coefficients are returned in the same registers. The registers 00–19 are required to store parameters.

4. Execution time for N data points

The execution time of the routines is tabulated in Table 1.

It can be seen that the execution time of DFT's is approximately proportional to N ln N, those of shuffling and print proportional to N, only conversion is slightly less than proportional to N. It should be kept in mind that a faster print out is achieved by pressing the keys: 20 2nd list.

5. Preparation of magnetic cards

When one of the program parts listed above has been keyed in it must be written on a magnetic card.

Attention: Before writing or reading a card make sure that memory partitioning is of the right order! (Press: 2nd Op 16 239.89 must be displayed. If not: press 9 2nd Op 17)

The cards should be marked as shown in Fig. 1.

Naturally the system of marking will be varied to suit one's own convenience, and this arrangement suggested here is only a recommendation and oriented around the hints on the display and the synonyms (Table 2).

Table 1 Execution times

Complex data

routine	execution time (s) for N = 8	N = 16	N = 32
BRING OUT	25	50	95
DFT forward	70	180	430
ARRANGE	27	60	110
DFT inverse	72	185	448
ARRANGE	20	45	85

Real data

routine	execution time (s) for N = 16	N = 32	N = 64
BRING OUT	27	51	95
DFT forward	73	180	432
ARRANGE	28	55	115
CONVERT	32	55	107
DFT inverse	73	180	433
ARRANGE	21	40	82
BRING OUT	30	50	95

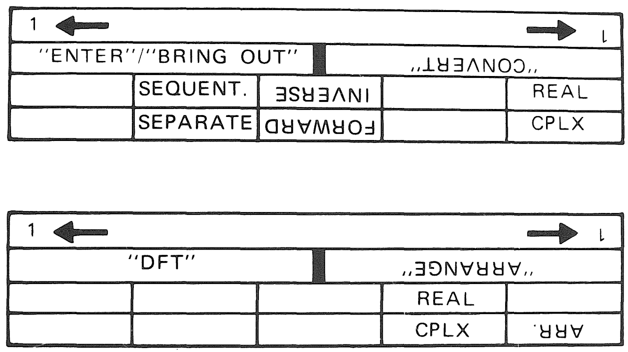

Fig. 1 Marking of magnetic cards

Table 2 Synonyms

Pgm. No.	user defined key	synonym	functions
0.1	E'	ENTER	Input, complex data
0.2	E	ENTER	Input, real data
0.3	B'	BRING OUT	Print out, complex data, real and imag. part separate
0.4	B	BRING OUT	Print out, sequential
1.1	D'	DFT	FFT forward, complex data
1.2	D	DFT	FFT forward, real data
1.3	SBR INV	DFT	FFT inverse
2	A	ARRANGE	Shuffling of FFT coeffs.
3.1	C	CONVERT	Conversion of FFT coeffs. after FFT forward
3.2	C'	CONVERT	Conversion of FFT coeffs. before starting FFT inverse

6. Program handling

Load one of the routines just described, paying attention to memory partitioning.

0. ENTER (input) and BRING OUT (output) routines

To permit a reliable data input the program consists of 2 parts. The display indicates in every case the index i of the data to be keyed in. Except when beginning an operation, the display "0" indicates that the operation is finished. An integer number displayed means that the real part of the data should be entered. Similarly, the input of the imaginary part is indicated by displaying "index of data.1".

0.1.1 ENTER N complex data

Program start
Key in: Number of data to put in
Press: 2nd E
Display: "O"
Program execution
Key in: Real part of first data x_0
Press: R/S
Display: "0.1"
Key in: Imag. part of first data x_0
Press: R/S
Display: "1"
Key in: Real part of x_1
Press: R/S
Display: "1.1"
Key in: Imag. part of x_1
etc.

0.1.2 ENTER 2 N real data

Program start
Key in: Half of the number of data to put in
Press: 2nd E
Display: "0"
Program execution
Key in: x_0
Press: R/S
Display: "0.1"
Key in: x_1
Press: R/S
Display: "1"
Key in: x_2
etc.

0.2 ENTER N complex data setting their imaginary parts generally to zero.

Program start
Key in: Number of data to put in
Press: E
Display: "0"
Program execution
Key in: Real part of x_0
Press: R/S
Display: "1"
Key in: Real part of x_1
Press: R/S
etc.

The BRING OUT routines are written to perform – as far as possible – a comfortable print out. There are 2 types of output:

1. Data are printed in the same sequence as stored in the data registers. The index of data is printed at the right side of the paper. This method may be preferred to print out real data. It can be used for complex data also, but the right side index is no longer suitable.
2. The real and imaginary parts of the data are printed separately.

0.3 Separate print of real and imaginary parts of data

Program start
Press: 2nd B
Print: "R"
"x_0" (real part) "00"
"x_1" (real part) "01"
.
.
.
"x_n" (real part) "n"

"I"
"x_0" (imag. part) "00"
"x_1" (imag. part) "01"
.
.
.
"x_n" (imag. part) "n"

0.4 Sequential BRING OUT

Program start
Press: B
Print: "CPLX"
"x_0" "00"
"x_1" "01"
"x_2" "02"
etc.

1. DFT (FFT)

1.1 DFT forward, complex data

Program start
Press: 2nd D
Display: "2" indicating that calculation is completed and ARRANGE/A must follow

1.2 DFT forward, real data

Program start
Press: D
Display: "2" as above

1.3 DFT inverse

Program start
Press: SBR INV
Display: "2" as above

2. ARRANGE (shuffling)

Program start
Press: A
Display: "0" indicating the end of operations
or: "3.1" indicating that calculation is completed and CONVERT/C must follow

3. CONVERT (only if real data were entered)

3. 1 CONVERT the result of DFT to DFT coefficients

Program start
Press: C
Display: "0" indicating the end of operations

3. 2 CONVERT DFT coefficients of real data to prepare inverse DFT

Program start
Press: 2nd C
Display: "1.3" indicating that calculation is completed and DFT/SRB INV must follow

7. Sequence of operations

Complex data, forward transform

ENTER/2nd E; [optionally: BRING OUT/2nd B]; DFT/2nd D; ARRANGE/A; BRING OUT/2nd B.

Complex data, inverse transform

CONVERT/2nd C; DFT/SRB INV; ARRANGE/A; BRING OUT/2nd B.

Real data can be transformed in two ways:
1. Real data are considered as complex data having imaginary parts equal to zero. In this case data can be entered according to 0.2.
2. Real data are entered in the data registers without regard to the fact that odd numbered registers are provided for the imaginary parts of complex data. This method needs an additional routine to convert the DFT coefficients. Nevertheless execution becomes faster and the maximum number of data points twice as large.

Real data, forward transform

ENTER/2nd E; [optionally: BRING OUT/B]; DFT/D; ARRANGE/A; CONVERT/C; BRING OUT/2nd B.

Real data, inverse transform

CONVERT/2nd C; DFT/SRB INV; ARRANGE/A; BRING OUT/B.

The characters right of the slash are a reference to the key to be pressed.

8. An example of application

Table 3 and Fig. 2 present a part of a spectrum obtained from EDS by adding a pure background of Bremsstrahlung from a carbon target to a pure peak

Table 3 Count rate and current index of a part of an EDS spectrum

CPLX				
	3726.	00	4340.	16
	3714.	01	4171.	17
	3734.	02	4248.	18
	3672.	03	4066.	19
	3668.	04	3947.	20
	3770.	05	3899.	21
	3720.	06	3897.	22
	3678.	07	3777.	23
	3724.	08	3771.	24
	3794.	09	3771.	25
	3893.	10	3636.	26
	3976.	11	3690.	27
	4093.	12	3667.	28
	3988.	13	3681.	29
	4120.	14	3658.	30
	4151.	15	3725.	31

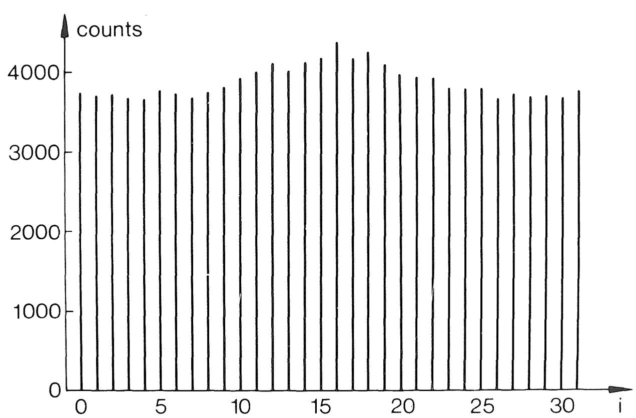

Fig. 2 Count rate and current index of a part of an EDS spectrum

generated by a Co_{57}-source. The sum of counts in all channels of the peak (peak integral) is 5,118 counts, the integral of peak plus background numbers 123,365 counts. The energy-scale is replaced by running numbers, the index i (i = 0, 1,..., N-1). The data are ordered so that the peak maximum is placed at N/2 and were entered in the calculator with the aid of routine "ENTER". 16 was keyed in and the program started by pressing "2nd E". Table 3 was printed out with "BRING OUT/B".

Thereafter "DFT" was loaded and executed by key "D" followed by "ARRANGE/A" and "CONVERT/C". The DFT coefficients now resident in the data registers were printed out by "BRING OUT/2nd B" as shown in Table 4. The two sets of numbers – indicated by "R" and "I" respectively – are the cosine- and sine-coefficients of the DFT.

Table 4 FFT coefficients of data points given in Table 3

R		I	
3855.15625	00	0.	00
-121.3611744	01	-3.517942454	01
53.66598451	02	-2.791983743	02
-6.582778884	03	-1.986192532	03
6.67428639	04	-7.712961078	04
-4.012319279	05	14.64237968	05
11.05892292	06	-7.206566881	06
-1.654167289	07	-4.407844716	07
.9375000003	08	-1.65625	08
-1.140785671	09	-4.591211761	09
-2.506645647	10	14.76063188	10
-4.92233112	11	.2923104881	11
4.95071361	12	-.4629610788	12
1.081214375	13	2.531825377	13
9.156738217	14	1.050215014	14
-14.90765773	15	3.416777606	15
9.96875	16	0.	16

As the sine-coefficients of a symmetric curve are zero, a first step to suppress the non-symmetric part (background) can be to set all sine-coefficients to zero. To get a smoothed backtransform the cosine-coefficient of higher frequencies should be cut off. In this example all cosine-coefficients starting at i = 11 were set to zero (to keep the example simple no attempt was made to suppress side lobes). Finally, the higher frequencies of the remaining coefficients should be raised. This was done by multiplying the coefficients, by a factor f_i (f_i = 0, 0.1, 0.2,..., 1.0 for i = 0, 1,..., 10). This is comparable with high pass filtering in analogue technique. Now the modified coefficients were transformed back by loading "CONVERT" and starting the routine by pressing "2nd C". Next steps: "DFT/SRB INV", "ARRANGE/A" and printing by "BRING OUT/B". The result of this procedure is given in Fig. 3. This method is sometimes used for peak sharpening and to facilitate peak detection.

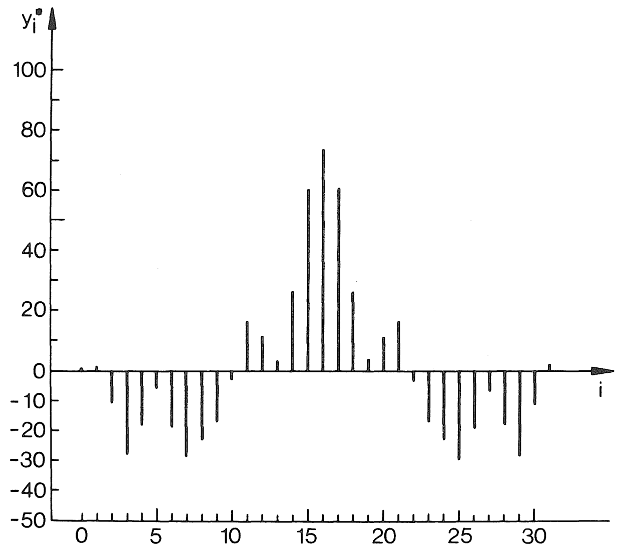

Fig. 3 Spectrum after high pass filtering and smoothing

This procedure however does not perform a quantitative separation of peak and background. To evaluate the peak integral use can be made of PARG (*Schwarz* 1977). This method of "Peak Analysis and Regeneration of a Gaussian Curve" is based on the following considerations:

A spectral peak should be of Gaussian form. The FFT coefficients of a Gaussian curve are also Gaussian.

If the peak follows the relation:

$$y_i = h\, e^{-\lambda\,(x_i - \bar{x})^2} \qquad (1)$$

then the cosine-coefficients a_n of DFT are given by:

$$|\,a_n\,| = \frac{h}{N}\sqrt{\frac{\pi}{\lambda}}\, e^{-\frac{n^2\,\pi^2}{N^2\,\lambda}} \qquad (2)$$

It can be shown that the coefficients a_1 und a_2 are nearly unaffected by the background under convenient conditions (given in this example!). In such a case a_o and the peak integral Σy_i are easy to calculate:

$$a_o = |\,a_1\,|\left|\frac{a_1}{a_2}\right|^{1/3} \quad ; \quad \Sigma y_i = a_o\,N \qquad (3)$$

In the example under discussion we obtain:
$a_o = 159.2966564$; $\Sigma y_i = 5097.5$

Compared with the theoretical value the error is about -0.4 %.

Table 5 Program listings

Routines: 0.1 – 0.4 ENTER/BRING OUT

```
000 76 LBL
001 15 E
002 71 SBR
003 00 00
004 22 22
005 43 RCL
006 02 02
007 91 R/S
008 72 ST*
009 01 01
010 02 2
011 44 SUM
012 01 01
013 69 OP
014 22 22
015 97 DSZ
016 00 00
017 00 00
018 05 05
019 00 0
020 91 R/S
021 91 R/S
022 47 CMS
023 42 STO
024 10 10
025 42 STO
026 00 00
027 65 ×
028 02 2
029 65 ×
030 42 STO
031 16 16
032 02 2
033 95 =
034 42 STO
035 15 15
036 55 ÷
037 08 8
038 95 =
039 42 STO
040 17 17
041 02 2
042 00 0
043 42 STO
044 01 01
045 92 RTN
046 76 LBL
047 10 E'
048 71 SBR
049 00 00
050 22 22
051 22 INV
052 86 STF
053 01 01
054 43 RCL
055 02 02
056 91 R/S
057 72 ST*
058 01 01
059 69 OP
060 21 21
061 87 IFF
062 01 01
063 00 00
064 74 74
065 93 .
066 01 1
067 44 SUM
068 02 02
069 86 STF
070 01 01
071 61 GTO
072 00 00
073 54 54
074 93 .
075 01 1
076 22 INV
077 44 SUM
078 02 02
079 69 OP
080 22 22
081 97 DSZ
082 00 00
083 00 00
084 51 51
085 00 0
086 91 R/S
087 91 R/S
088 76 LBL
089 17 B'
090 69 OP
091 00 00
092 03 3
093 05 5
094 69 OP
095 01 01
096 02 2
097 61 GTO
098 01 01
099 17 17
100 76 LBL
101 12 B
102 69 OP
103 00 00
104 01 1
105 05 5
106 03 3
107 03 3
108 02 2
109 07 7
110 04 4
111 04 4
112 69 OP
113 00 00
114 69 OP
115 01 01
116 01 1
117 42 STO
118 04 04
119 42 STO
120 05 05
121 00 0
122 42 STO
123 01 01
124 86 STF
125 01 01
126 01 1
127 00 0
128 00 0
129 42 STO
130 03 03
131 01 1
132 42 STO
133 02 02
134 02 2
135 00 0
136 44 SUM
137 01 01
138 43 RCL
139 16 16
140 42 STO
141 00 00
142 01 1
143 32 X:T
144 43 RCL
145 11 11
146 22 INV
147 67 EQ
148 01 01
149 53 53
150 02 2
151 44 SUM
152 00 00
153 43 RCL
154 05 05
155 22 INV
156 49 PRD
157 00 00
158 08 8
159 32 X:T
160 98 ADV
161 69 OP
162 05 05
163 43 RCL
164 03 03
165 85 +
166 43 RCL
167 02 02
168 95 =
169 69 OP
170 04 04
171 73 RC*
172 01 01
173 69 OP
174 06 06
175 43 RCL
176 05 05
177 44 SUM
178 01 01
179 69 OP
180 22 22
181 43 RCL
182 02 02
183 67 EQ
184 02 02
185 05 05
186 97 DSZ
187 00 00
188 01 01
189 62 62
190 22 INV
191 97 DSZ
192 04 04
193 02 02
194 37 37
195 69 OP
196 00 00
197 02 2
198 04 4
199 69 OP
200 01 01
201 01 1
202 61 GTO
203 01 01
204 22 22
205 87 IFF
206 01 01
207 02 02
208 24 24
209 01 1
210 42 STO
211 02 02
212 08 8
213 32 X:T
214 01 1
215 00 0
216 00 0
217 44 SUM
218 03 03
219 86 STF
220 01 01
221 61 GTO
222 01 01
223 86 86
224 22 INV
225 86 STF
226 01 01
227 01 1
228 00 0
229 42 STO
230 02 02
231 01 1
232 03 3
233 32 X:T
234 61 GTO
235 01 01
236 86 86
237 00 0
238 91 R/S
239 91 R/S
```

Routines: 1.1 – 1.3 DFT

```
000 76 LBL
001 19 D'
002 01 1
003 94 +/-
004 42 STO
005 12 12
006 42 STO
007 11 11
008 61 GTO
009 00 00
010 27 27
011 76 LBL
012 14 D
013 01 1
014 42 STO
015 11 11
016 94 +/-
017 42 STO
018 12 12
019 61 GTO
020 00 00
021 27 27
022 76 LBL
023 22 INV
024 01 1
025 42 STO
026 12 12
027 70 RAD
028 43 RCL
029 10 10
030 42 STO
031 14 14
032 23 LNX
033 55 ÷
034 02 2
035 23 LNX
036 95 =
037 42 STO
038 00 00
039 43 RCL
040 14 14
041 42 STO
042 13 13
043 55 ÷
044 02 2
045 95 =
046 42 STO
047 14 14
048 42 STO
049 05 05
050 55 ÷
051 89 π
052 95 =
053 35 1/X
054 42 STO
055 15 15
056 53 (
057 43 RCL
058 05 05
059 75 -
060 01 1
061 54 )
062 65 ×
063 43 RCL
064 15 15
065 95 =
066 42 STO
067 03 03
068 39 COS
069 48 EXC
070 03 03
071 38 SIN
072 65 ×
073 43 RCL
074 12 12
075 95 =
076 42 STO
077 04 04
078 43 RCL
079 10 10
080 42 STO
081 08 08
082 53 (
083 43 RCL
084 08 08
085 75 -
086 43 RCL
087 13 13
088 85 +
089 43 RCL
090 05 05
091 54 )
092 65 ×
093 02 2
094 85 +
095 01 1
096 09 9
097 95 =
098 42 STO
099 06 06
100 85 +
101 43 RCL
102 13 13
103 95 =
104 42 STO
105 07 07
106 73 RC*
107 06 06
108 42 STO
109 02 02
110 85 +
111 73 RC*
112 07 07
113 22 INV
114 44 SUM
115 02 02
116 95 =
117 72 ST*
118 06 06
119 69 OP
120 36 36
121 69 OP
122 37 37
123 73 RC*
124 06 06
125 42 STO
126 01 01
127 85 +
128 73 RC*
129 07 07
130 22 INV
131 44 SUM
132 01 01
133 95 =
134 72 ST*
135 06 06
136 36 PGM
137 04 04
138 13 C
139 72 ST*
140 07 07
141 69 OP
142 27 27
143 32 X:T
144 72 ST*
145 07 07
146 43 RCL
147 13 13
148 75 -
149 01 1
150 95 =
151 22 INV
152 44 SUM
153 08 08
154 97 DSZ
155 08 08
156 00 00
157 82 82
158 97 DSZ
159 05 05
160 00 00
161 56 56
162 97 DSZ
163 00 00
164 00 00
165 39 39
166 98 ADV
167 69 OP
168 00 00
169 03 3
170 01 1
171 01 1
172 07 7
173 04 4
174 04 4
175 03 3
176 07 7
177 00 0
178 00 0
179 69 OP
180 01 01
181 06 6
182 04 4
183 00 0
184 00 0
185 01 1
186 03 3
187 03 3
188 05 5
189 03 3
190 05 5
191 69 OP
192 02 02
193 01 1
194 03 3
195 03 3
196 01 1
197 02 2
198 02 2
199 01 1
200 07 7
201 00 0
202 00 0
203 69 OP
204 03 03
205 06 6
206 03 3
207 01 1
208 03 3
209 00 0
210 00 0
211 00 0
212 00 0
213 00 0
214 00 0
215 69 OP
216 04 04
217 69 OP
218 05 05
219 02 2
220 91 R/S
221 91 R/S
222 00 0
223 00 0
224 00 0
225 00 0
226 00 0
227 00 0
228 00 0
229 00 0
230 00 0
231 00 0
232 00 0
233 00 0
234 00 0
235 00 0
236 00 0
237 00 0
238 00 0
239 00 0
```

Routine: 2 ARRANGE

```
000 76 LBL
001 18 C'
002 01 1
003 94 +/-
004 42 STO
005 11 11
006 65 ×
007 76 LBL
008 13 C
009 01 1
010 95 =
011 42 STO
012 19 19
013 70 RAD
014 00 0
015 42 STO
016 08 08
017 02 2
018 01 1
019 42 STO
020 06 06
021 85 +
022 43 RCL
023 10 10
024 42 STO
025 07 07
026 95 =
027 44 SUM
028 07 07
029 42 STO
030 05 05
031 43 RCL
032 17 17
033 42 STO
034 09 09
035 69 OP
036 35 35
037 02 2
038 64 PD*
039 05 05
040 69 OP
041 25 25
042 94 +/-
043 64 PD*
044 05 05
045 29 CP
046 43 RCL
047 19 19
048 22 INV
049 77 GE
050 00 00
051 64 64
052 43 RCL
053 21 21
054 72 ST*
055 07 07
056 69 OP
057 37 37
058 43 RCL
059 20 20
060 72 ST*
061 07 07
062 69 OP
063 27 27
064 73 RC*
065 06 06
066 42 STO
067 01 01
068 75 -
069 73 RC*
070 07 07
071 44 SUM
072 01 01
073 95 =
074 72 ST*
075 06 06
076 94 +/-
077 72 ST*
078 07 07
079 69 OP
080 36 36
081 69 OP
082 37 37
083 73 RC*
084 07 07
085 42 STO
086 02 02
087 85 +
088 73 RC*
089 06 06
090 22 INV
091 44 SUM
092 02 02
093 95 =
094 72 ST*
095 06 06
096 72 ST*
097 07 07
098 89 π
099 55 ÷
100 43 RCL
101 10 10
102 65 ×
103 43 RCL
104 08 08
105 95 =
106 42 STO
107 00 00
108 39 COS
109 65 ×
110 43 RCL
111 19 19
112 95 =
113 42 STO
114 03 03
115 43 RCL
116 00 00
117 38 SIN
118 94 +/-
119 42 STO
120 04 04
121 36 PGM
122 04 04
123 13 C
124 74 SM*
125 06 06
126 22 INV
127 74 SM*
128 07 07
129 69 OP
130 26 26
131 69 OP
132 27 27
133 32 X:T
134 74 SM*
135 06 06
136 74 SM*
137 07 07
138 69 OP
139 26 26
140 69 OP
141 26 26
142 69 OP
143 37 37
144 69 OP
145 37 37
146 69 OP
147 28 28
148 97 DSZ
149 09 09
150 00 00
151 63 63
152 98 ADV
153 29 CP
154 43 RCL
155 19 19
156 77 GE
157 02 02
158 12 12
159 69 OP
160 00 00
161 03 3
162 01 1
163 01 1
164 07 7
165 04 4
166 04 4
167 03 3
168 07 7
169 00 0
170 00 0
171 69 OP
172 01 01
173 06 6
174 04 4
175 00 0
176 00 0
177 01 1
178 06 6
179 02 2
180 01 1
181 03 3
182 07 7
183 69 OP
184 02 02
185 06 6
186 03 3
187 03 3
188 06 6
189 01 1
190 04 4
191 03 3
192 05 5
193 69 OP
194 03 03
195 02 2
196 04 4
197 03 3
198 01 1
199 04 4
200 02 2
201 00 0
202 00 0
203 69 OP
204 04 04
205 69 OP
206 05 05
207 01 1
208 93 .
209 03 3
210 91 R/S
211 91 R/S
212 69 OP
213 00 00
214 01 1
215 07 7
216 03 3
217 01 1
218 01 1
219 06 6
220 69 OP
221 03 03
222 69 OP
223 05 05
224 00 0
225 91 R/S
226 91 R/S
227 00 0
228 00 0
229 00 0
230 00 0
231 00 0
232 00 0
233 00 0
234 00 0
235 00 0
236 00 0
237 00 0
238 00 0
239 00 0
```

Routines: 3.1 – 3.2 CONVERT

```
000 76 LBL
001 11 A
002 01 1
003 42 STO
004 03 03
005 42 STO
006 04 04
007 43 RCL
008 17 17
009 42 STO
010 00 00
011 43 RCL
012 10 10
013 75 -
014 01 1
015 95 =
016 42 STO
017 01 01
018 42 STO
019 02 02
020 43 RCL
021 04 04
022 65 ×
023 02 2
024 95 =
025 42 STO
026 06 06
027 32 X:T
028 01 1
029 08 8
030 44 SUM
031 06 06
032 43 RCL
033 03 03
034 65 ×
035 02 2
036 95 =
037 42 STO
038 05 05
039 77 GE
040 00 00
041 62 62
042 01 1
043 08 8
044 44 SUM
045 05 05
046 73 RC*
047 05 05
048 63 EX*
049 06 06
050 72 ST*
051 05 05
052 69 OP
053 25 25
054 69 OP
055 26 26
056 73 RC*
057 05 05
058 63 EX*
059 06 06
060 72 ST*
061 05 05
062 43 RCL
063 04 04
064 32 X:T
065 43 RCL
066 00 00
067 77 GE
068 00 00
069 83 83
070 22 INV
071 44 SUM
072 04 04
073 55 ÷
074 02 2
075 95 =
076 32 X:T
077 43 RCL
078 04 04
079 32 X:T
080 61 GTO
081 00 00
082 67 67
083 44 SUM
084 04 04
085 69 OP
086 23 23
087 97 DSZ
088 02 02
089 00 00
090 20 20
091 29 CP
092 43 RCL
093 12 12
094 77 GE
095 01 01
096 89 89
097 02 2
098 00 0
099 42 STO
100 01 01
101 43 RCL
102 16 16
103 42 STO
104 00 00
105 43 RCL
106 11 11
107 22 INV
108 77 GE
109 01 01
110 13 13
111 04 4
112 65 ×
113 43 RCL
114 10 10
115 95 =
116 22 INV
117 64 PD*
118 01 01
119 69 OP
120 21 21
121 97 DSZ
122 00 00
123 01 01
124 16 16
125 98 ADV
126 43 RCL
127 11 11
128 22 INV
129 77 GE
130 01 01
131 89 89
132 69 OP
133 00 00
134 03 3
135 01 1
136 01 1
137 07 7
138 04 4
139 04 4
140 03 3
141 07 7
142 00 0
143 00 0
144 69 OP
145 01 01
146 06 6
147 04 4
148 00 0
149 00 0
150 01 1
151 05 5
152 03 3
153 02 2
154 03 3
155 01 1
156 69 OP
157 02 02
158 04 4
159 02 2
160 01 1
161 07 7
162 03 3
163 05 5
164 03 3
165 07 7
166 00 0
167 00 0
168 69 OP
169 03 03
170 06 6
171 03 3
172 01 1
173 05 5
174 00 0
175 00 0
176 00 0
177 00 0
178 00 0
179 00 0
180 69 OP
181 04 04
182 69 OP
183 05 05
184 03 3
185 93 .
186 01 1
187 91 R/S
188 91 R/S
189 69 OP
190 00 00
191 01 1
192 07 7
193 03 3
194 01 1
195 01 1
196 06 6
197 69 OP
198 03 03
199 69 OP
200 05 05
201 00 0
202 91 R/S
203 91 R/S
204 00 0
205 00 0
206 00 0
207 00 0
208 00 0
209 00 0
210 00 0
211 00 0
212 00 0
213 00 0
214 00 0
215 00 0
216 00 0
217 00 0
218 00 0
219 00 0
220 00 0
221 00 0
222 00 0
223 00 0
224 00 0
225 00 0
226 00 0
227 00 0
228 00 0
229 00 0
230 00 0
231 00 0
232 00 0
233 00 0
234 00 0
235 00 0
236 00 0
237 00 0
238 00 0
239 00 0
```

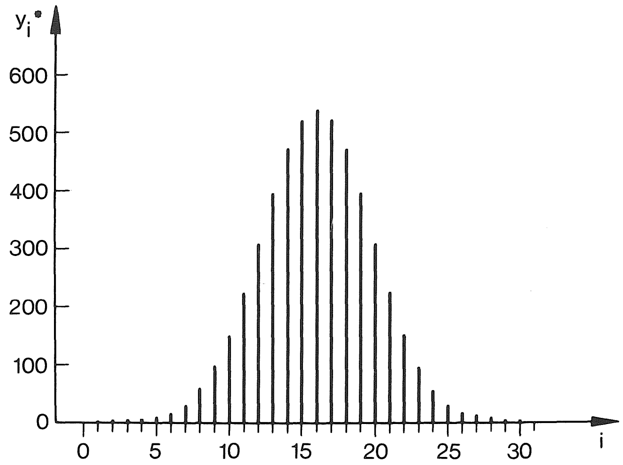

Fig. 4 Gaussian peak regenerated by PG

The total peak can be regenerated using the equation:

$$y_i^* = h\, e^{-\lambda(i - \bar{i})^2} \quad (i = 0, 1, \ldots, N\text{-}1)\ (\bar{i} = N/2) \qquad (4)$$

$$\text{where } \lambda = \frac{3\pi^2}{N^2} \frac{1}{\ln \left| \frac{a_1}{a_2} \right|} \quad ; \quad h = a_o N \sqrt{\frac{\lambda}{\pi}} \qquad (5)$$

(see Fig. 4)

Of course the use of FFT does not seem to be very economical if only the first two cosine-coefficients are needed, but this is only intended to serve as an example.

9. Final remarks

It would be admirable if the manufacturer of the TI 59 calculator could create a solid state software module having versatile FFT and utility routines. As there would then be much less restriction in respect of the program length, the I/O routines would become more comfortable and the FFT could be accomplished for a mixed radix. This would result not only in quicker and more convenient handling but in a slightly greater number of data registers being available. Reloading of routines (5 in the example above) would be omitted.

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