Program Name: FILTER

Language: Compiled BASIC

Microcomputer Use: IBM-PC and compatibles, PC-DOS 2.0, color monitor, memory capacity of 64K or more, and optional printer.

Purpose: FILTER is used to design digital filter equations for inclusion in other computer programs.

Program Input/Output: Digital filters can be completely designed using FILTER. Keyboard entries are required for filter specification. Graphs of filter response are presented on the screen to judge adequacy of the specified filter. Filter equations are also presented on the screen, with optional paper copy.

Program Interfaces. FILTER requires PC-DOS 2.0 or higher. Copies of FILTER are supplied on 9-sector disks (DOS 3.0). Filter response curves may be printed by pressing keys: "Shift" and "Print Screen." **Note: "Shift" and "Print Screen" will not work on Windows machines in DOS.**

Program Description: FILTER uses the bilinear transformation with frequency prewarping to form a digital filter from an analog filter specified by the user. The user is required to choose among lowpass, highpass, bandpass, and bandstop filter types, and between Butterworth and Chebyshev filter families. To assist in these choices, some basic information is provided should the user require it. The number of filter poles must be chosen by the user, but an elaborate nomographic design aid is provided should it be required. Other filter parameters are requested by the program.

Once filter specifications have been completely given, the program determines analog filter terms in two steps: first, normalized lowpass filter terms are calculated, and, second, an unnormalized analog filter of the type specified is obtained from the

normalized filter. The digital filter is obtained from the unnormalized analog filter.

Analog filter and digital filter frequency response can be checked in both tabular and print plot form on the screen. The low-resolution print plot allows a quick check of filter shape, as well as allowing numerical values of filter magnitude to be printed opposite graphed points. Different graph limits may be specified by the user in case certain frequency ranges must be scrutinized in more detail.

Digital filter equations are calculated and presented in sequential fashion. That is, the input parameter of the present equation is the output value of the next equation. Equations represent one or two digital filter poles.

If desired, a sample program may be displayed incorporating the digital filter just designed. The program is given in BASIC, and allows the user to incorporate the filter by inserting the listed program segment in the appropriate position in his computer program. This program segment may be listed on the printer as well as on the screen. Using this program segment, there is no ambiguity in application of the filter equations determined previously.

Filter temporal response is the last portion of FILTER. Filter response is first given for five different frequency sine waves, representing the entire range of filter responses. After that, a square wave response is calculated for a clean and a noisy square wave. If the user checks the program listing for this segment, he will find the implementation of the filter to be different from, and more efficient than, the sample program given above.

Error checking is incorporated within FILTER. Invalid responses and impossible specifications are not allowed.

FILTER relies heavily on use of color, and should be used with a color monitor. Without a color monitor, all program operations will still be performed.

All program screen plots may be printed on a printer by simultaneously pressing "shift" and "prt sc." Screen plots in the graphics mode requires GRAPHICS.COM to be residing in memory in order to make a hard copy. This is automatically accomplished by the AUTOEXEC.BAT file provided on the disk.

Program Components: FILTER is supplied on a 5¼" diskette. There are five required files and five optional files. The required files are:

FILTER.EXE	62903 bytes	7-11-86
FILTERF.EXE	7015 bytes	7-11-86
FILTERT.EXE	5223 bytes	7-11-86
FILTERP.EXE	20471 bytes	7-11-86
BASRUN20.EXE	63232 bytes	6-25-85

and the optional files are:

FILTER.ASC	58341 bytes	7-11-86
FILTERF.ASC	5768 bytes	7-11-86
FILTERT.ASC	3529 bytes	7-11-86
FILTERP.ASC	19279 bytes	7-11-86
AUTOEXEC.BAT	18 bytes	7-11-86

The first four files are filter programs written in BASIC and compiled using IBM BASIC Compiler version 2.0. The file BASRUN20.EXE is required to run the first four.

The four .ASC files are uncompiled BASIC versions of the above four .EXE files. They are stored in ASCII, and may be listed under either BASIC or DOS. They will also execute under BASICA, but will be found to be much slower than the compiled form. An AUTOEXEC.BAT file has been supplied for automatic loading and running of the file.

Program Use: FILTER is highly interactive and friendly to users who are somewhat familiar to filter terminology. All questions are intended to be easily understood by those who have been previously exposed to frequency-selective filters.

To begin FILTER, just put the FILTER disk in your computer and turn on the computer. If the disk you are using does not contain DOS, BASRUN20.EXE, and AUTOEXEC files, this procedure will not work. In that case, initialize the computer with a DOS disk and load BASICA.COM and GRAPHICS.COM. Replace the system disk with the FILTER disk, and load FILTER.ASC. Run the program.

Answer the questions as they arise. Most specification entries must be followed by an "enter," whereas other entries do not require an "enter." Specification assistance is available for help with filter type, filter family, and number of poles. The last is particularly useful, and probably will be used often. Other filter specifications, such as important frequencies, filter attenuations, and digital sampling rates must be supplied, with assistance, by the user.

Filter response plots are intended for screen presentation only. They may, however, be printed on paper by simultaneously pressing "Shift" and "Prt Sc." Provision in FILTER is made for printing filter equations.

Program Example: Follow program directions until you see:

TYPES OF FILTERS:

respond with "A". You will see a display of type characteristics.

push any key

respond "1"

FAMILIES OF FILTERS:

respond with A. You will see an explanation of the difference between Butterworth and Chebyshev filters.

press any key
press any key

respond "1"

NUMBER OF FILTER POLES:

respond "A", "enter". You will see a display similar to figure 1.

WHAT IS THE VALUE OF 'fc' (cps)?

respond "2", "enter

WHAT IS THE VALUE OF 'fs' (cps)?

respond "4", "enter"

WHAT IS THE VALUE OF ATTENUATION 'A max' (dB)?

respond "3", "enter"

WHAT IS THE VALUE OF ATTENUATION 'A min' (dB)?

respond "9", "enter". The blinking star should be between lines 1 and 2, indicating a two-pole filter should be used. See figure 2.

ARE YOU SATISFIED WITH THESE RESULTS?

respond "S"

NUMBER OF POLES =

respond "2", "enter"

FREQUENCY OF INTEREST:

respond "2", "enter"

ATTENUATION ...

respond "M", "enter"

WHAT MULTIPLE OF 3 dB DO YOU WISH?

respond "1", "enter"

ARE THERE ANY CHANGES?

respond "N"

DIGITAL FILTER SPECIFICATION:

respond "S"

HOW MANY SAMPLES PER CYCLE?

respond "20", [r]enter"

ARE THERE ANY CHANGES TO BE MADE?

respond "N"

DO YOU WISH TO SEE THE PLOT OF THE ANALOG FILTER RESPONSE?

respond "Y". You will see a plot similar to figure 3.

DO YOU WISH A DIFFERENT PLOT?

respond "N"

DO YOU WISH TO SEE A PLOT OF THE DIGITAL FILTER RESPONSE?

respond "Y". The number of samples under "phase angle" is the delay of the filter in terms of sampling intervals. You will see a plot similar to figure 4.

DO YOU WISH A DIFFERENT PLOT?

respond "Y"

ENTER NEW MINIMUM FREQUENCY:

respond "20", "enter"

ENTER NEW MAXIMUM FREQUENCY:

respond "50", "enter"

ENTER NEW MAGNIFICATION:

respond "1" "enter"

ENTER NEW LENGTH:

respond "20", "enter". You will see a plot similar to figure 5.

DO YOU WISH A DIFFERENT PLOT?

respond "N"

DO YOU WISH TO SEE THE DIGITAL FILTER EQUATIONS?

respond "Y"

DO YOU WISH TO MAKE A COPY OF THESE EQUATIONS ON THE PRINTER?

respond "Y". You will see the equations on the screen as well as have a paper copy similar to listing 1.

DO YOU WISH TO SEE THE PROGRAM?

respond "Y".

DO YOU WISH TO LIST THE PROGRAM ON THE PRINTER?

respond "Y". You will see a listing similar to listing 2.

DO YOU WISH TO DISPLAY TEMPORAL RESPONSE OF YOUR FILTER TO THESE INPUTS?

respond "Y". You will first see a screen plot similar to figure 6.

Press any key, and you will see a screen plot similar to figure 7.

Press any key

DO YOU WISH TO DESIGN ANOTHER FILTER?

Respond "N".

Reference: Johnson, A. T., 1985, Microcomputer Programs for the Design of Digital Filters, Computer Programs in Biomedicine 21:203-210.

WHAT IS THE VALUE OF FREQUENCY ‘fc’ (cps)?

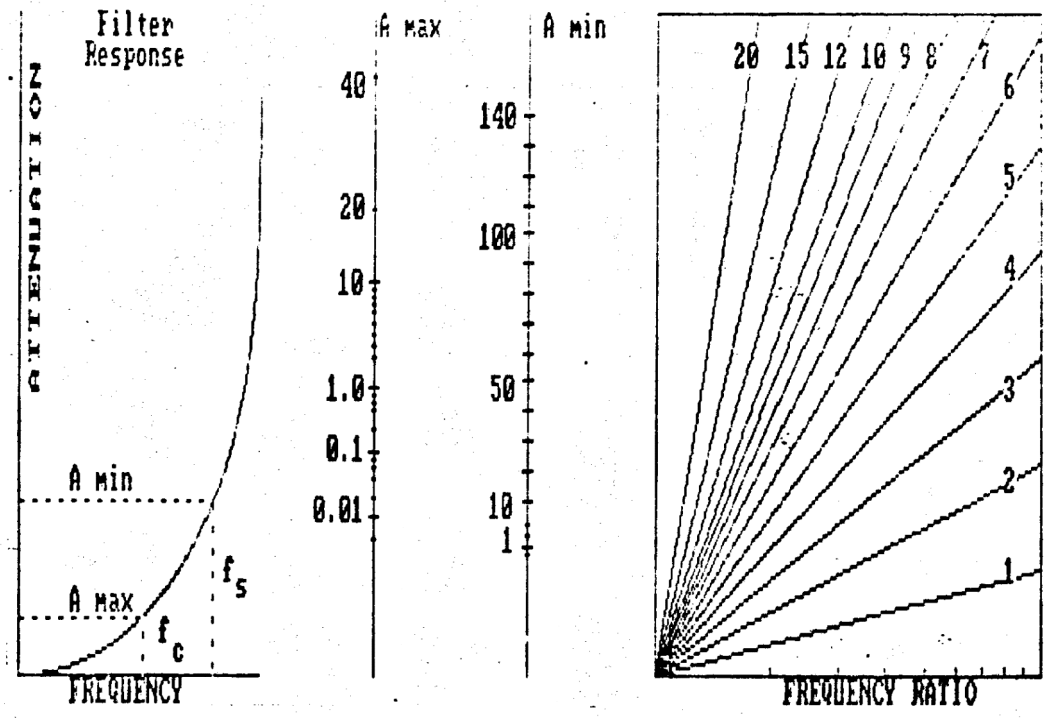

Figure 1

THE NUMBER OF FILTER POLES IS THE VALUE OF THE HIGHER INTEGER FROM THE LINES NEAREST THE BLINKING STAR. PRESS ANY KEY TO CONTINUE...

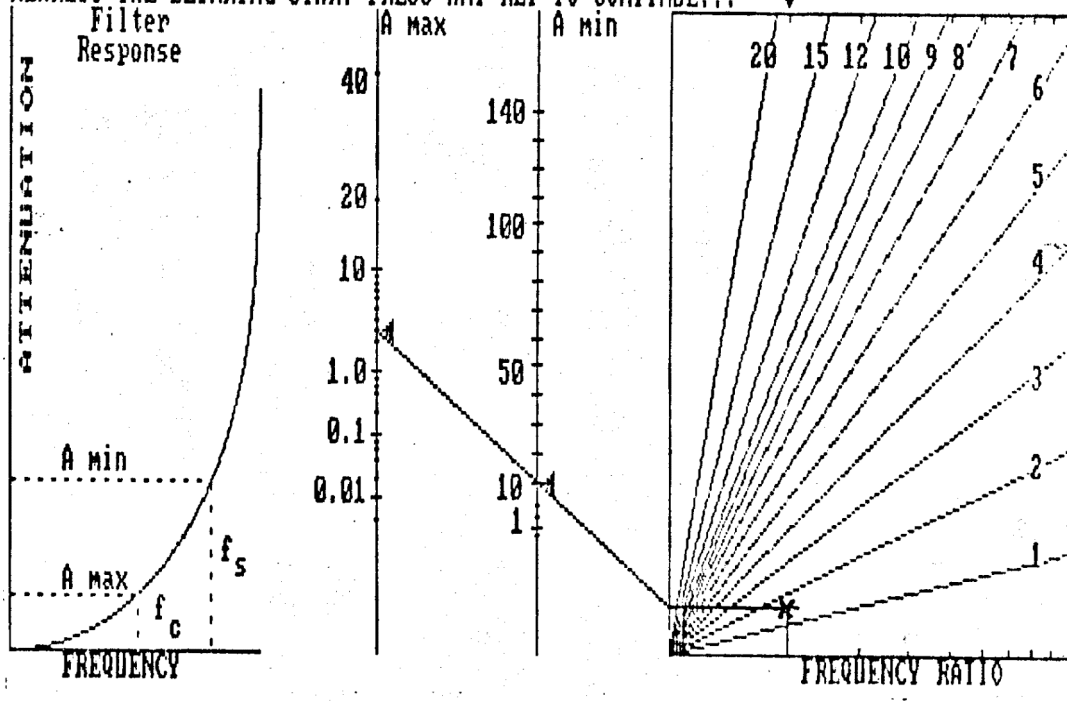

Figure 2

LOGARITHMIC FREQUENCY PLOT OF THE ANALOG BUTTERWORTH LOWPASS FILTER WITH 2 POLES

FREQUENCY	MAGNITUDE actual	MAGNITUDE dB	PHASE ANGLE degrees	PHASE ANGLE radians	MAGNITUDE PLOT 0 ... 1
.02866	1.0000	+.00000	-1.16	-.020	*
.05256	1.0000	-.00000	-2.13	-.037	*
.09639	1.0000	-.00002	-3.91	-.068	*
.17678	.99997	-.00027	-7.18	-.125	*
.32421	.99965	-.00300	-13.2	-.231	*
.59460	.99612	-.03380	-24.8	-.432	*
1.0905	.95854	-.36784	-47.7	-.832	*
2.0000	.70711	-3.0103	-90.0	-1.57	*
3.6680	.28497	-10.904	-132.	-2.31	*
6.7272	.08805	-21.106	-155.	-2.71	*
12.338	.02627	-31.611	-167.	-2.91	*
22.627	.00781	-42.144	-173.	-3.02	*
41.499	.00232	-52.680	-176.	-3.07	*
76.109	.00069	-63.216	-178.	-3.10	*
139.58	.00021	-73.752	-179.	-3.12	*
256.00	.00006	-84.288	-179.	-3.13	*

DO YOU WISH A DIFFERENT PLOT? (Y/N)

Figure 3

LOGARITHMIC FREQUENCY PLOT OF THE DIGITAL BUTTERWORTH LOWPASS FILTER WITH 2 POLES

FREQUENCY	MAGNITUDE actual	MAGNITUDE dB	PHASE ANGLE degrees	PHASE ANGLE samples	MAGNITUDE PLOT 0 ... 1
.02866	1.0000	+.00009	-1.15	-4	*
.05256	.99998	-.00015	-2.11	-4	*
.09639	1.0000	+.00003	-3.88	-4	*
.17678	.99996	-.00035	-7.12	-4	*
.32421	.99966	-.00298	-13.1	-5	*
.59460	.99624	-.03271	-24.6	-5	*
1.0905	.95941	-.35989	-47.4	-5	*
2.0000	.70711	-3.0103	-90.0	-5	*
3.6680	.27469	-11.223	-133.	-4	*
6.7272	.07343	-22.683	-157.	-3	*
12.338	.01183	-38.539	-171.	-2	*
22.627	.00110	-59.178	-2.69	0	*
41.499	.87340	-1.1757	-67.3	0	*
76.109	.24443	-12.237	-43.5	0	*
139.58	.00003	-91.462	-180.	0	*
256.00	.00265	-51.541	-176.	0	*

DO YOU WISH A DIFFERENT PLOT? (Y/N)

Figure 4

FREQUENCY	MAGNITUDE actual	dB	PHASE ANGLE degrees	samples	MAGNITUDE PLOT 0 1
20.000	.00000	∞	-90	-1	*
20.988	.00015	-76.380	-.999	0	*
22.025	.00065	-63.802	-2.06	0	*
23.113	.00156	-56.128	-3.20	0	*
24.255	.00302	-50.386	-4.46	0	*
25.454	.00523	-45.630	-5.87	0	*
26.711	.00850	-41.414	-7.49	0	*
28.031	.01338	-37.473	-9.41	0	*
29.416	.02087	-33.609	-11.8	0	*|
30.869	.03297	-29.637	-14.9	0	*|
32.395	.05414	-25.330	-19.2	0	| *
33.995	.09600	-20.355	-25.9	0	| *
35.675	.19692	-14.114	-38.4	0	| *
37.437	.51612	-5.7450	-70.1	0	| *
39.287	.99226	-.06749	-150.	0	| *
41.228	.93690	-.56610	-54.0	0	| *
43.265	.34276	-9.3002	-127.	0	| *
45.403	.12199	-18.273	-151.	0	| *
47.646	.05340	-25.449	-161.	0	| *
50.000	.02508	-32.014	-167.	0	*|

DO YOU WISH A DIFFERENT PLOT? (Y/N)

Figure 5

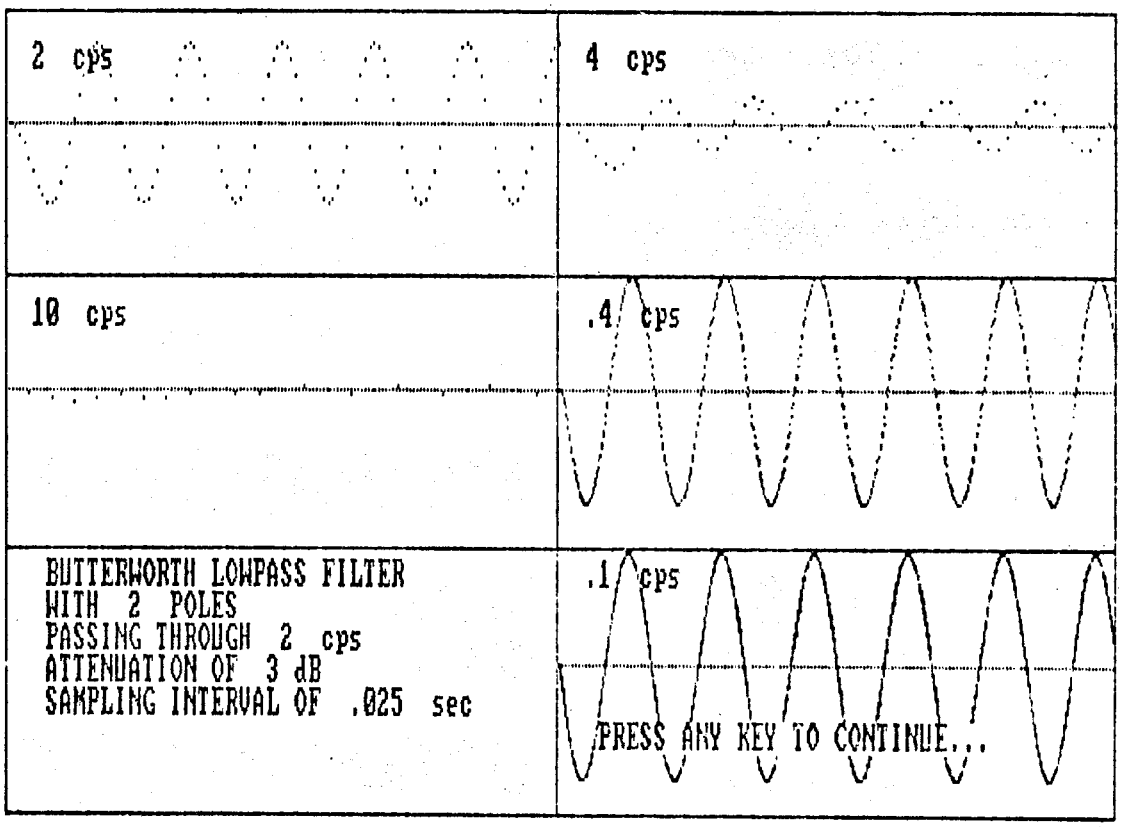

Figure 6

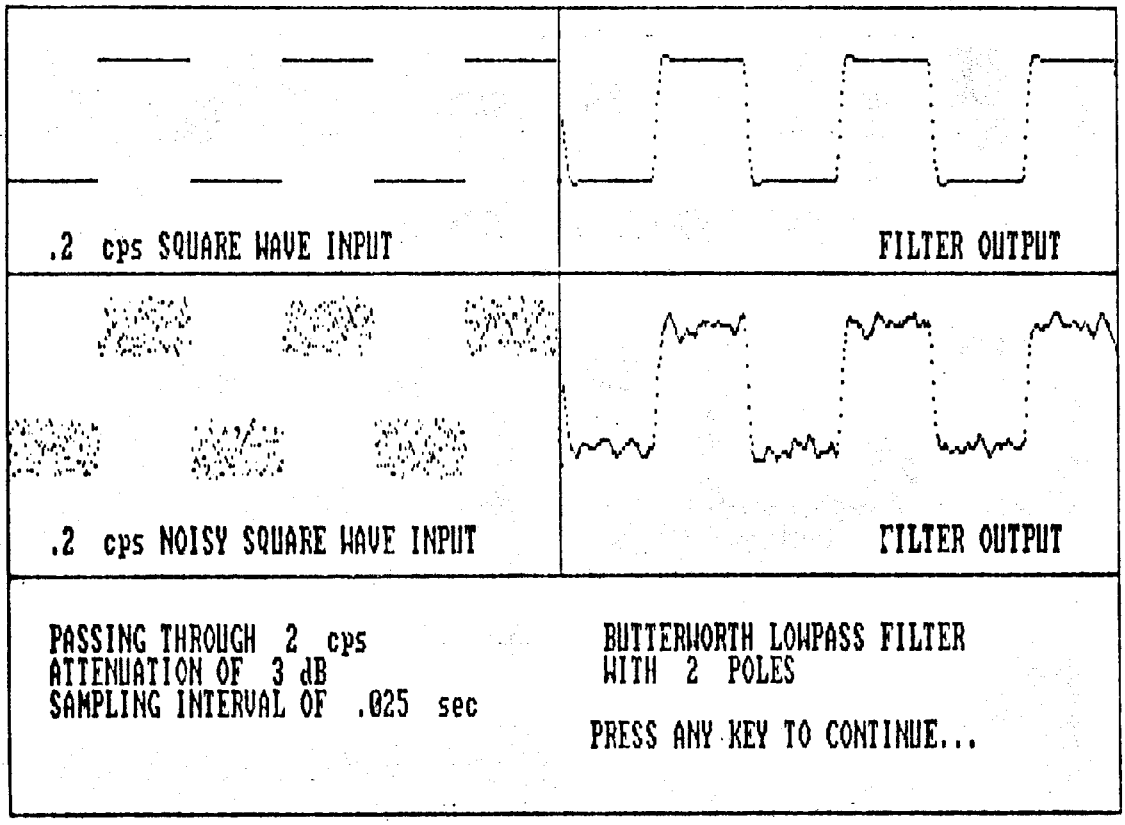
.2 cps SQUARE WAVE INPUT
FILTER OUTPUT
.2 cps NOISY SQUARE WAVE INPUT
FILTER OUTPUT
PASSING THROUGH 2 cps
ATTENUATION OF 3 dB
SAMPLING INTERVAL OF .025 sec
BUTTERWORTH LOWPASS FILTER
WITH 2 POLES
PRESS ANY KEY TO CONTINUE...

Figure 7

DIGITAL FILTER EQUATIONS

BUTTERWORTH LOWPASS FILTER 02-13-1985
WITH 2 POLES
PASSING THROUGH 2 cps
ATTENUATION OF 3 dB
SAMPLING INTERVAL OF 0.25 sec

X(K) = DATA INPUT

Y(K) = [X(K) + 2X(K-1)+ X(K-2) +AY(K-1) + BY(K-2)]/C

WHERE: A = 77.72691
B = -31.93446
C = 49.79245

Y(K) = FILTER OUTPUT

Listing 1

DIGITAL FILTER PROGRAM

BUTTERWORTH LOWPASS FILTER 02-13-1985
WITH 2 POLES
PASSING THROUGH 2 cps
ATTENUATION OF 3 dB
SAMPLING INTERVAL OF 0.25 sec

```
1020  X3 = X2 :  X2 = X1
1030  REM **********INCOMING DATA IS PUT INTO X1 HERE**********
1040  Y3 = Y2 :  Y2 = Y1
1050  Y1 = (X1+2*X2+X3+ 77.72691 *Y2-31.93446 *Y3)/ 49.79245
1060  REM **********Y1 IS THE CURRENT OUTPUT OF THE FILTER**********
```

Listing 2