EE 338 Digital Signal Processing

Filter Design Assignment: Spring Semester: January - April 2025

This is an **individual** filter design assignment for each student who has registered for the course. The specification of the filter(s) to be designed by a given student is provided according to the filter number M assigned to the student, which filter number will be informed in due course.

A large number of filter specifications have been provided corresponding to each filter number M. **However, it will be mandatory for each student to design filters, with only <u>some</u> of these specifications, for <u>some</u> of the filter types, that are described in the sequel.** The specifics, including scheme for award of credit in this assignment, shall be announced as the course proceeds, in due course.

Protocol for Filter Design

In the filter design, you are encouraged to partly make use of SCILAB or any equivalent open source software/ freeware as available. You are encouraged to contact the Computer Centre/ the PC Laboratory in the Department of Electrical Engineering for more information on open source software available in the Institute. It is not mandatory to use any package, of course! You could write a C program / high level language program as well. For designing the IIR and FIR filters, you are NOT permitted to use "complete filter design" commands directly. Neither are you permitted to carry out the whole design simply by using a filter design package or by employing ChatGPT like tools. You may use basic SCILAB or equivalent statements relating to matrix operations, window function generation, and so on. You may write small programs on your own, in these open source softwares/ freeware. You are welcome to consult one another in the class during your designs, to assist one another. However, the final design must be done individually by each student, albeit with assistance from other students of the course.

It is recommended, though not mandatory, that each design be reviewed and certified by one other student. It is also recommended that every student in this course review *up to, meaning not more than, 3 designs of a particular type of filter.* Reviews are recommended only by students who have gained reasonable confidence in the design. In a design submission, the student submitting the design and the student reviewing and certifying it, if any, must be clearly specified, with names and roll numbers. The ideal thing to do, is to review each other's assignment in a student group if each group member feels competent to do so.

Design submissions for each Filter Type, mandatory or optional, must be as follows, in an electronic file to be uploaded appropriately, as per instructions from Teaching Associates, to be given in due course. Each student needs to submit a separate file for each filter type, that s/he designs in this assignment.

A. Write, on top, your name, roll number, filter number M and the name + roll number of your colleague(s), who reviewed and certified your design.

B. The following data pertinent to each of the filter designs must be submitted, in that order.

1. The un-normalized discrete time filter specifications: including whether the passband(s) and stopband(s) are equiripple/ oscillatory or monotonic/ non-oscillatory, respectively, if applicable.

2. The corresponding normalized digital filter specifications.

3. **If it is an IIR Filter being designed**, the design process followed, which includes:

(a) corresponding analog filter specifications for the same type of analog filter(s), using the bilinear transformation. The frequency transformation(s) to be employed with all the relevant parameters used in the design.

(b) The specifications of the frequency transformed lowpass analog filter(s).

(c) The analog lowpass filter transfer function(s) $H_{analog,\ LPF}(s_{\mathrm{L}})$.

(d) The analog transfer function(s) for the appropriate type of filter.

(e) The discrete time filter transfer function.

4. **If it is an FIR Filter Design**, then an FIR Filter Transfer function for realizing the specifications using the Kaiser Window, where applicable.

5. **Evidence of the correctness** of the design, including the frequency response of the filter.

6. An overall **comparison between different realizations**, for the same specifications, **where applicable**, in the task.

7. **Optional: A review report** from the colleague, who reviewed and certified your design. Teaching Associates will specify the format of this review report.

You may use a program statement for generating the Kaiser window coefficients directly. As it is tedious to write out coefficients and data by hand each time, you are welcome to include an electronic write-out of results/ data from a computer program, wherever appropriate. Further, you must give reliable evidence of the frequency response of the filters that you have designed.

The Band Specifications:

All frequencies are in kiloHertz (kHz). There are two groups of frequency bands, which will be used in specifying the filters ahead. For each group of frequency bands, we pass the argument D, which is an integer ranging from 0 to 10. The frequency band in each group is specified according to the argument D.

M=79, Q=7, R=2

Group I of Frequency Bands: The frequency band in this group is

$$(40 + 5D)\ to\ (70 + 5D)$$

75 to 105

Group II of Frequency Bands: The frequency band in this group is

$$(170 + 5D)\ to\ (200 + 5D)$$

180 to 210

Consider a filter number M assigned to a student. Write the (integer) number $M = 11\,Q + R$, where Q is the quotient upon dividing M by 11 and R is the remainder.

For example, when

$M = 93, Q = 8$ and $R = 5$,
since 93 divided by 11 yields 8 as the quotient and 5 as the remainder.

Now, for this student with Filter Number M, the frequency band from Group I can be obtained by passing the argument $D = Q$ and the frequency band from Group II can be obtained by passing the argument $D = R$.

Design Tasks: An analog signal is bandlimited to 280 kHz. It is ideally sampled, with a sampling rate of 630 kHz. We wish to build a series of discrete time filters, as described below, to extract specific frequency bands of an analog signal or to suppress specific frequency bands of the signal.

(i) For all filters, the passband AND stopband tolerances are 0.15 in magnitude. That is, the filter magnitude response (note: NOT magnitude squared) must lie between 1.15 and 0.85 in the passband; and between 0 and 0.15 in the stopband. For the IIR Filter, the passband magnitude response must lie between 1 and 0.85.

(ii) For bandpass filters, the transition bands are 5 kHz on either side of each passband. For bandstop filters, the transition bands are 5 kHz on either side of each stopband.

Use either Butterworth, Chebyshev or Elliptic approximation, to design the IIR Filters as appropriate. For the FIR Filter, use the Kaiser window.

Filter Type 1 for a given student: IIR Multi-Band pass Filter, with bands from both Group I and Group II acting as **monotonic/ non-oscillatory** passbands. The remaining stopbands are all **monotonic/ non-oscillatory**.

Filter Type 2 for a given student: IIR Multi-Band pass Filter, with bands from both Group I and Group II acting as **equiripple/ oscillatory** passbands. The remaining stopbands are all **monotonic/ non-oscillatory**.

Filter Type 3 for a given student: IIR Multi-Band pass Filter, with bands from both Group I and Group II acting as **equiripple/ oscillatory** passbands. The remaining stopbands are all **equiripple/ oscillatory**.

Filter Type 4 for a given student: IIR Multi-Band stop Filter, with bands from both Group I and Group II acting as **monotonic/ non-oscillatory** stopbands. The remaining passbands are all **monotonic/ non-oscillatory**.

Filter Type 5 for a given student: IIR Multi-Band stop Filter, with bands from both Group I and Group II acting as **monotonic/ non-oscillatory** stopbands. The remaining passbands are all **equiripple/ oscillatory**.

Filter Type 6 for a given student: IIR Multi-Band stop Filter, with bands from both Group I and Group II acting as **equiripple/ oscillatory** stopbands. The remaining passbands are all **equiripple/ oscillatory**.

Filter Type 7 for a given student: FIR Multi-Band pass Filter, with bands from both Group I and Group II acting as **passbands**.

Filter Type 8 for a given student: FIR Multi-Band stop Filter, with bands from both Group I and Group II acting as **stopbands**.

Here are some possibilities, from which you can choose, for designing these filters:

P1. **Cascade** of one bandpass filter and one bandstop filter, with appropriate specifications.

P2. **Cascade** of two bandstop filters, with appropriate specifications.

P3. Two bandpass filters or two bandstop filters, with appropriate specifications, **in parallel**.