

Project – Active Filter

Introduction. Specifications. Logbook. Requirements for design approval. Testing. Presentation and oral exam. Topics for discussion. Tips.

Introduction

Your firm is currently developing an embedded system that requires analog signal-conditioning circuitry on its analog inputs. You have been assigned the task of designing an active analog filter that will be suitable for manufacture.

The filter is to meet the following thermal, electrical, EMC and mechanical specifications. It is envisaged that the filter will perform appropriate signal extraction from a noisy waveform to enable a reliable estimate of the RMS value by the microcontroller.

Preliminary designs should be finalised with your project supervisor during the Week 5 schematic review session.

It is your responsibility to manufacture a printed circuit assembly (PCA) based on your design, i.e. a complete printed circuit board (PCB) with all components mounted.

One prototype unit, together with supporting documentation, is to be supplied for evaluation by the date specified in the timetable. Late submission will incur penalties.

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Specifications

Electrical

Each unit will meet the following **electrical** specifications:

- (i) DC power is to originate from a 50 Hz AC supply of 12V RMS which is rated to deliver 1A RMS, with a 2.5 mm plug.
- (ii) DC voltages are to be within 3% of nominal value with peak-to-peak ripple less than 0.5% of nominal value.
- (iii) The power consumption is to be less than 400 mW.
- (iv) The input signal voltage is differential, with a range ± 2.5 V.
- (v) The input is known to have a 20 V RMS 50 Hz common-mode noise voltage on it with respect to the power supply common. This needs to be suppressed by at least 80 dB.
- (vi) The differential input impedance is to be 100 k Ω or greater.
- (vii) The output voltage is single-ended, with a range of 0 V to 5V. The filter output should be DC level shifted, of value $+2.5$ V \pm 2%.
- (viii) The output impedance is to be 50 Ω \pm 1%.
- (ix) The output voltage is to be hard limited so that the minimum voltage falls within 0 V to -0.9 V and the maximum voltage falls within 5 V to 5.9 V, with negligible signal distortion between 0 V and 5 V.
- (x) PCBs are to use SMT where possible. For manufacturing ease, the **minimum** track width is to be 0.15 mm, **minimum** track spacing is to be 0.2 mm, and all vias are to have a 0.5 mm hole size with a 0.8 mm diameter pad. A 2 mm border is to be kept free of copper around the edge of the board.

(xi) See **Table 1** for details of the filter specification as given below:

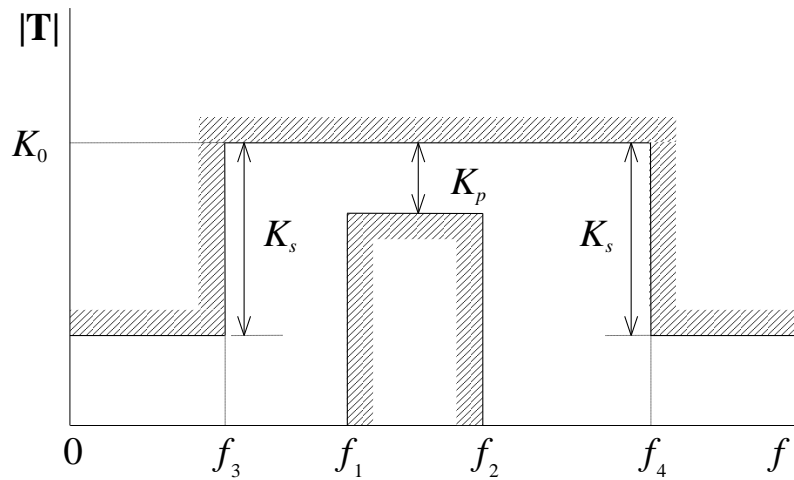


Table 1 - Bandpass Filter

Spec. No.	Passband frequencies $f_1 - f_2$ (Hz)	Maximum passband gain, K_0 (dB)	Maximum passband attenuation, K_p (dB)	Stopband frequencies, f_3, f_4 (Hz)	Minimum stopband attenuation K_s (dB)
1	300 - 3000	0	0.8	100, 10000	10
2	300 - 4000	0	0.8	100, 15000	10
3	300 - 5000	0	0.8	50, 15000	10
4	300 - 6000	0	0.8	100, 20000	10
5	350 - 3000	0	0.8	100, 15000	15
6	350 - 4000	0	0.8	100, 15000	15
7	350 - 5000	0	0.8	100, 20000	15
8	350 - 6000	0	0.8	50, 21000	15
9	400 - 3000	0	0.8	50, 12000	20
10	400 - 4000	0	0.8	100, 20000	20
11	400 - 5000	0	0.8	50, 20000	20
12	400 - 6000	0	0.8	100, 25000	20
13	450 - 3000	0	1.2	150, 10000	20
14	450 - 4000	0	1.2	150, 15000	20
15	450 - 5000	0	1.2	200, 12000	20
16	450 - 6000	0	1.2	160, 18000	20
17	410 - 590	0	0.8	250, 1000	20
18	430 - 570	0	0.8	200, 980	20
19	450 - 550	0	0.8	100, 990	30
20	470 - 530	0	0.8	250, 1000	35

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Thermal

Each unit will meet the following **thermal** specifications:

- (xii) Operating ambient temperature -5°C to $+50^{\circ}\text{C}$.
- (xiii) Electronic components are to adhere to the reliability temperature limits as listed in **Table 2**.

Table 2 - Operating Limits for Good Reliability

Type of Component	Maximum Temperature
Field effect transistor	125°C junction
Diodes, except LED	125°C junction
LED	110°C junction
Linear semiconductor	105°C junction
Digital semiconductor	110°C junction
Hybrid semiconductor	110°C junction
VLSI, FPGA, μP , μC	125°C junction
Memory	125°C junction
Capacitor	Max. ambient rating $+10^{\circ}\text{C}$
Resistor - composition	Max. ambient rating $+30^{\circ}\text{C}$
Resistor - film	Max. ambient rating $+40^{\circ}\text{C}$
Resistor – wirewound, accurate	Max. ambient rating $+10^{\circ}\text{C}$
Resistor – wirewound, power	Max. rating or 125°C case
Potentiometer	Max. ambient rating $+35^{\circ}\text{C}$
Inductor	Hot spot rating $+15^{\circ}\text{C}$

Electromagnetic Compatibility (EMC)

Each unit will meet the following **EMC** specifications:

- (xiv) Where applicable, each unit will meet the conducted and radiated RFI of AS/NZS CISPR 14.1:2013.
- (xv) Each unit shall follow “good practice” in its layout to minimise EMI internally and externally.
- (xvi) Each unit must be shielded from power frequency (50 Hz or 60 Hz) magnetic fields.

Mechanical

Each unit will meet the following **mechanical** specifications:

- (xvii) Input and output signal terminals on the PCB are to be screw terminals (for ease of connection when testing).
- (xviii) All components to be housed in a metal enclosure of **maximum** dimensions 65 mm x 100 mm x 45 mm.
- (xix) All electrical leads entering or leaving a metal enclosure will be securely anchored to the enclosure.
- (xx) All signal leads will pass through the outer walls of the enclosure through appropriate electrical connectors or cable glands.
- (xxi) All exposed surfaces of a metal enclosure will be protected from corrosion.

Note:

A comprehensive CAD package for mechanical design is Autodesk’s Inventor:

<http://www.autodesk.com/education/free-software/inventor-professional>

Autodesk provide free education licences valid for 3 years.

Environmental

Each unit will meet the following **environmental** specifications:

- (xxii) The product lifetime is to be 10 years.
- (xxiii) Each unit will meet the collection, storage, transport and treatment of end-of-life electrical and electronic equipment requirements as outlined in AS/NZS 5377:2013.

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Logbook

Good engineering is likely to come from good professional habits. In the context of a company, a task that is not documented did not happen. A task that is not well documented did not happen well.

As a member of a firm, you are obliged (as a matter of basic professional practice) to maintain a comprehensive log of work that is easily comprehensible by replacement staff (should you be transferred to another task) and by following staff (should the project be successful). It is recommended that you adhere to the following guidelines.

- The “logbook” is to be in electronic format, such as *Microsoft® OneNote®*, that can be easily organised into sections and pages. It will detail project design, measurements and testing during the life of the project, together with other details, such as relevant theory and circuit analysis, design time estimates and costing.
- You should create relevant sections based on the different subsystems (e.g. analog filter, power supply), and within each section you should record your work chronologically.
- Calculations carried out on loose sheets of paper will be penalised. **The logbook should contain all of your jottings, calculations, circuits etc. as they occur.**
- The logbook should be “cloud-based”, so that you can access it anywhere and make it available for discussion at any time.
- You should keep the logbook **up-to-date**, with all material pertinent to the design work included. Relevant pages from device datasheets should be included for easy reference.
- The book should be intelligible to others that follow you, as noted above. Therefore, a logical framework, clarity and neatness are required. Experiments and tests that failed must be part of the document, to avoid others following the same false trails.
- The progress of the project should be clear to any assessor with an examination of the logbook. To that end the logbook should be written in clear English language, with entries in sufficient detail to enable easy understanding. **Reasons for decisions concerning the design or modifications to any aspect of the design must be clearly explained.**

Format

- Relevant headings and subheadings used for different sections.
- All entries dated, entries easy to read.
- All design material (e.g. datasheet extracts) placed into logbook.

Content

In each of the following sections relevant material should be recorded. The **REASONS** for your choices/decisions associated with the design should be **FULLY EXPLAINED**. Discuss any problems along with suggested solutions.

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Section 1

- Your own objectives for this subject.
- A table containing a detailed list of activities to be completed, an estimation of time in hours required and the actual time spent on each.
- An overview of relevant background theory (general filter theory and specific details e.g. on the biquad or Friend circuits) for filter design. A consideration of other possible designs and the **reasons for choosing your particular design**.
- Design approach to meet **each** of the electrical specifications of the circuit, e.g. gain, input/output impedances, level shifting etc.
- A block diagram of the overall system.
- A full schematic of your design that includes any custom components, has proper component labelling, uses appropriate connectivity methods (net labels, ports, etc.) and incorporates a parameter table that includes full component details (e.g. part number, rating, type, manufacturer, supplier). A bill of materials should also be produced, that incorporates the full component details.
- How you chose appropriate components, with relevant data sheets. Include an analysis of **ALL** the relevant characteristics of the various passive and active components e.g. offset voltage and bandwidth of an op-amp, tolerance and type of dielectric for a capacitor. Calculations should be performed to support the analysis. Vague generalisations such as “the tolerance should be as small as possible” are **not** acceptable.

Section 2

- The design approach to meet the EMC specifications, e.g. inputs and outputs meet conducted EMC requirements, strategies to minimise common impedance, capacitive and inductive coupling, proper power supply distribution and decoupling.
- The design considerations for the layout of the PCB including size, track widths, component placement etc. as well as a printout of each layer of the PCB.
- A spatial visualisation including a front panel layout and an isometric view with covers removed showing major component locations. A consideration of connectors and / or cable entry. Show all dimensions in mm.
- Costing of the entire project from design through to manufacture. Cost of testing / calibration (if any). Make assumptions about labour costs, overheads, etc., or use your experience.
- The methods and results of **ALL** tests carried out on the prototype, including hardware fix-ups and testing.
- A summary of specifications as achieved in the final design.

As marks for the logbook will be based on the above items make sure that you submit each item.

Requirements for the Schematic Review

You must bring your **up-to-date** logbook to the schematic review session.

Your logbook should contain the following:

1. Your **own** objectives for this subject. Don't just copy those from the subject guide!
2. A table containing a **detailed** list of activities to be completed during the semester and an estimation of time (hours) required for each as well as actual time spent on each to date.
3. An overview of relevant background theory (e.g. active filter design, power supplies).
4. Design approach to meet each of the electrical specifications of the circuit e.g. analog signal conditioning, level shifting, output impedance, etc.
5. A block diagram of your design, with as much detail as possible, e.g. choice of analog interface circuit topology, type of op-amp, etc.
6. A consideration of other possible designs and the **reasons for choosing your particular design**.
7. A preliminary schematic.

Requirements for the PCB Review

You must have an **up-to-date** logbook for the PCB review session.

Your logbook should contain the following:

1. Complete schematics of the design, including manufacturer part numbers and datasheets, with mechanical footprint details.
2. A bill of materials.
3. Design strategy to conform to good EMC practice.

Your PCB design will be reviewed in Altium during the session.

Testing

You must have an **up-to-date** logbook for the testing session.

Each of the following sections will be tested in the laboratory.

Power

- Voltages generated are within tolerance.
- Noise is minimised with appropriate power supply filtering.

Functional Testing

- Common-mode noise rejection.
- Input impedance.
- Output impedance.
- DC level shifting.
- Output limiting.

Filter

- Achievement of functional specifications – passband and stopband specifications.

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Presentation and Oral Exam

Your presentation is for an audience of senior engineers, and takes the form of a design review (imagine you are making a case for moving your design from a prototype to a marketable product).

You should outline the overall concept of your design, and then focus on what you consider to be unique or advantageous aspects of your design. Include a consideration of manufacturability, cost and ease of calibration / installation.

Presentation

The following are general guidelines for the presentation:

- Duration is between 10 and 15 minutes.
- Should be created using *Microsoft® PowerPoint®* presentation manager.
- Maximum of 10 slides (counting the title page).
- Slides with full schematics may be used as an “appendix” to the presentation. That is, they do not contribute to the 10 slide limit, and they do not form an integral part of the presentation. They are so that any technical questions can be answered in a timely fashion.

Oral Exam Questions

There are ten topics. Only **FIVE** will be chosen by the subject coordinator in the question time at the end of your presentation (the oral exam).

- The question time is between 15 and 20 minutes.
- The subject coordinator will ask questions first. Fellow students will then be invited to critique / ask questions if time permits.

Topics for Discussion

1. Explain how the power supply was chosen / designed – including the selection of appropriate components. What part of your design consumes the most amount of power, and why? What can you do to minimise the power consumption?
2. Explain your choice of op-amp, including a quantitative analysis of various op-amp imperfections such as bandwidth, offset voltage, bias currents, slew rate, output current limiting, etc.
3. What is the purpose of a sensitivity analysis, and how can it be performed?
4. Explain *quantitatively* how your output signal conditioning circuit works, i.e. the level shifter, the hard limiter and output impedance.
5. Explain how you tested your design – experimental setup, equipment used, expected results, specifications, etc.
6. Reflect on your design. Suggest improvements. What will you do differently in a similar project?
7. How would you minimise the cost of volume production (>1 000 units) of your device?
8. Discuss the steps taken to conform to good EMC practice in your design (components, PCB layout, enclosure etc).
9. Explain the method / circuit you used to suppress the common-mode noise on your analog input.
10. Discuss the various uses and types of capacitors in your circuit.

Tips

Some general tips are listed below.

1. Don't use general purpose op-amps without considering their BW and slew rate. These two important parameters will impact on the performance of the filter, and general purpose op-amps are usually not suitable for this particular filter application.
2. Be aware that sensitivity let's you know two things – whether a particular circuit topology is sensitive, and by how much particular components affect the response. If the circuit doesn't work when simulated with worst-case component tolerance, it will not work reliably in real life!
3. The process of undertaking this task is important, i.e. project management. Time management is a key, and prototyping with through-hole components is desirable.
4. Understand the operation of your circuit from a qualitative point-of-view.
5. The power supply capacitors should be chosen based on at least the voltage rating, ripple voltage and current ratings.
6. If using a difference amplifier, know how it works. They have limitations.
7. Organise for a “standard set of manufacturing requirements” to be adhered to when designing the PCB. This will make panelising and manufacturing easier and cheaper.
8. Provide test points and “links” at key locations. Isolating the power supply circuitry during PCB population can be very handy.
9. Buy more parts than you need – you will inevitably require spares, and lead times can be a problem.