

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2016-2017

EE6402 – REAL-TIME DSP DESIGN AND APPLICATIONS

November/December 2016

Time Allowed: 3 hours

INSTRUCTIONS

1. This paper contains 5 questions and comprises 6 pages.
2. Answer all 5 questions.
3. All questions carry equal marks.
4. This is a closed-book examination.

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1. Figure 1 shows a 3-tap linear phase FIR filter. The input and output signals at time n are $x(n)$ and $y(n)$, respectively, and are integers represented using two's complement. The products $2^{-2}x(n)$ and $2^{-1}x(n)$ are also represented using two's complement and are converted to integers immediately after multiplication by truncation, i.e. discarding the fractional bits of the product. Let the truncation process be modelled by: Truncated value = Original value + Error.

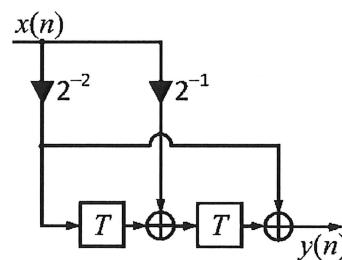


Figure 1

- (a) For $x(n) = -9$, what are the truncated values of $2^{-2}x(n)$ and $2^{-1}x(n)$?
(2 Marks)
- (b) Draw a diagram showing the rounding error's probability function for the coefficient whose value is 2^{-2} .
(2 Marks)

Note: Question No. 1 continues on page 2

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- (c) Determine the d.c. bias and a.c. noise power for the rounding error in part (b). (5 Marks)
- (d) Draw a diagram showing the rounding error's probability function for the coefficient whose value is 2^{-1} . (2 Marks)
- (e) Determine the d.c. bias and a.c. noise power for the rounding error in part (d). (4 Marks)
- (f) Assuming that the rounding errors for parts (b) and (d) are uncorrelated, determine the d.c. bias and a.c. noise spectrum in $y(n)$ due to rounding error. (5 Marks)

2. (a) Express the impulse response of the filter $H_1(z)$ given by

$$H_1(z) = \frac{1 + z^{-1}}{1 + 0.3z^{-1} + 0.1z^{-2}}$$

in the form $H_1(z) = h_1(0) + h_1(1)z^{-1} + h_1(2)z^{-2} + \dots$ up to and including the z^{-6} term.

(6 Marks)

- (b) Express the impulse response of the filter $H(z)$ given by

$$H(z) = \frac{(1 + z^{-1})(1 + 0.3z^{-1})}{1 + 0.3z^{-1} + 0.1z^{-2}}$$

in the form $H(z) = h(0) + h(1)z^{-1} + h(2)z^{-2} + \dots$ up to and including the z^{-6} term.

(4 Marks)

- (c) Figure 2 in page 3 shows an IIR filter. The input signal $x(n)$ at time n is arbitrary but its magnitude is bounded by unity. In order to avoid overflow, K_1 and K_2 must be selected to ensure that the magnitudes of $d(n)$, and $y(n)$ are bounded by unity. Determine K_1 and K_2 so that $|d(n)|$ and $|y(n)|$ are as large as possible but are not out of range.

(10 Marks)

Note: Question No. 2 continues on page 3

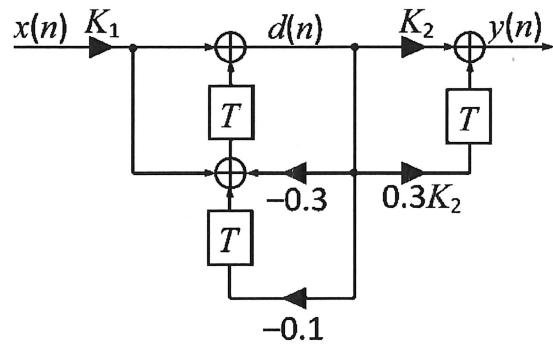
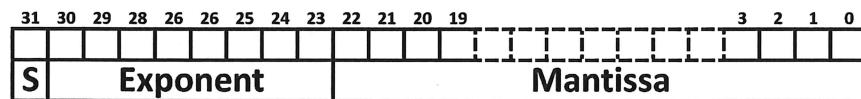


Figure 2

3. (a) Figure 3 shows the IEEE 754 standard for 32-bit binary floating-point arithmetic.

	Exponent	Mantissa
Nans	255, i.e. all 1s	Non zero
Infinities	255, i.e. all 1s	0
Zeroes	0, i.e. all 0s	0
Denormalized Numbers	0, i.e. all 0s	Non zero
Normalized Numbers	1 to 254. Biased binary	Any number



For normalized number

$$\text{Value} = (-1)^S 2^{Exp-127} \times 1.\text{(value represented by fractional bit)}$$

For denormalized number

Value = $(-1)^{S-1} 2^{-126} \times 0.(value\ represented\ by\ fractional\ bit)$

Figure 3

Note: Question No. 3 continues on page 4

Determine the following quantities represented in IEEE 754 standard.

(10 Marks)

- (b) A baseband signal bandlimited to $\pm B/2$ is carrier modulated at frequency f_c . The modulated signal is sampled at frequency f_s .

 - (i) Using the sampled signal spectrum, explain how the shaded forbidden zone in Figure 4 can be obtained, where m is a positive integer and $R = (2f_c + B)/2B$.
 - (ii) If $f_c = 20 \text{ MHz}$ and $B = 4 \text{ MHz}$, and an additional 0.5 MHz spectral separation is necessary for analog filtering, find the lowest value for f_s which avoids spectral aliasing.

(10 Marks)

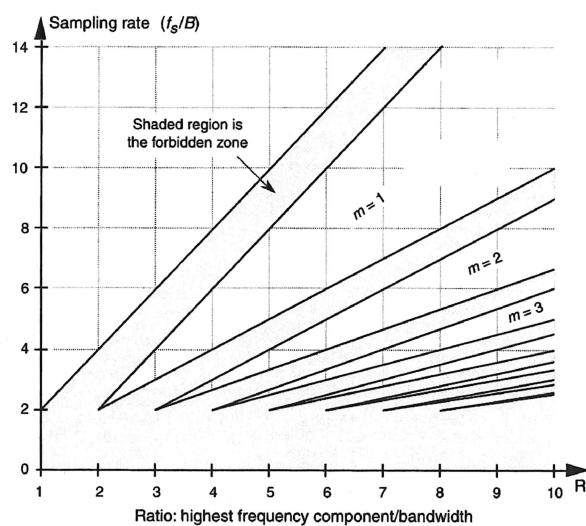


Figure 4

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4. (a) With the usual notation, the input-output relation of a 1st order $\Sigma - \Delta$ modulator is given by

$$Y(z^{-1}) = X(z^{-1}) + (1 - z^{-1})N(z^{-1}) .$$

Obtain a block diagram to describe the above relation and show how you could extend it to obtain a 2nd order $\Sigma - \Delta$ modulator. Explain why a bit resolution gain can be obtained when $\Sigma - \Delta$ modulators are used in analog-to-digital converters.

(7 Marks)

- (b) Figure 5 describes the operations performed by the auxiliary register arithmetic unit (ARAU) in a digital signal processor. Explain these operations highlighting the importance of using auxiliary registers (ARs), ARAU and auxiliary register pointer (ARP) for real-time operations.

(7 Marks)

- (c) A real-time signal processing system usually requires interrupt management working together with task scheduling. Explain the importance of task scheduling and using a timing diagram show the interaction between interrupts and task scheduling.

(6 Marks)

Operand	Operation
*	None
* ₊	$AR_n \leftarrow AR_n + 1$
* ₋	$AR_n \leftarrow AR_n - 1$
* ₀₊	$AR_n \leftarrow AR_n + AR_0$
* ₀₋	$AR_n \leftarrow AR_n - AR_0$
* _{BR0+}	$AR_n \leftarrow AR_n + AR_0$ with bit reversed carry
* _{BR0-}	$AR_n \leftarrow AR_n - AR_0$ with bit-reversed carry

Figure 5

5. (a) Digital signal processors (DSPs) use circular addressing which performs multiplications and additions in parallel in a single clock cycle. An L -length finite impulse response (FIR) filter is implemented on a DSP. The DSP requires $(L + 1)$ clock cycles to compute a filter output sample and 10% of time is necessary for overheads. If the DSP clock cycle time is 50 ns, what would be the maximum FIR filter length when it is used for real-time processing at 200 kHz?
(5 Marks)
- (b) Explain how the following features of a DSP helps in implementing FIR filters in real-time.
- (i) Instruction pipelining with 6 phases (pre-fetch, fetch, decode, access, read and execute),
 - (ii) Circular buffers with RPTZ instruction and BK register,
 - (iii) Use of RPTB instruction and BRC register.
(7 Marks)
- (c) Incomplete code fragment implementing an FIR filter on a DSP is shown below. The 32 length filter is implemented in block processing mode with a block size of 200. Giving reasons, insert appropriate numerical values (after # signs) for proper operation of the code. Also explain the operations of MAC and STH instructions in the program.

```
STM      # , BK
STM      # , AR0
STM      # , BRC

RPTB    loop-1
RPTZ    A, #
MAC     *AR3+0%, *AR2+, A
STH     A, *AR4+
MAR     *+AR2(#)

loop:  
(8 Marks)
```

END OF PAPER

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2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.
3. Please write your Matriculation Number on the front of the answer book.
4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.