

12.5 IIR filter design

Name: _____ Class: _____ Date: _____

Total: 24 marks

KEY WORDS bilinear transform • prewarp

Objective

Prewarp cutoffs, transform analog prototypes, and verify the digital result at dc and at the cutoff.

1 Key knowledge and worked examples

■ The bilinear transform

$s = \frac{2}{T} \cdot \frac{1-z^{-1}}{1+z^{-1}}$: left half-plane maps inside the unit circle (stability free), frequencies warp by $\omega_a = \frac{2}{T} \tan(\omega_d T/2)$ – prewarp every critical frequency.

■ Worked example: the 100 Hz biquad

$f_s = 1$ kHz: prewarp $\omega_a = 2000 \tan(0.1\pi) = 649.8$ rad/s, $K = 1/\tan(0.1\pi) = 3.078$, and the 2nd-order Butterworth becomes $H(z) = \frac{1+2z^{-1}+z^{-2}}{14.82-16.94z^{-1}+6.12z^{-2}}$ ✓.

■ Verify, then pay

DC gain $4/4 = 1.000$ ✓; $|H|$ at 100 Hz = -3.0 dB ✓ (cutoff placed exactly); poles at $|z| = 0.643$ ✓. Skip the prewarp ($K = 1$) and it cuts at 250 Hz – silently off-spec. The bill: 5 coefficients vs 67 taps, nonlinear phase, sensitive denominators.

2 Practice

2.1 Prewarp a 250 Hz cutoff at $f_s = 1$ kHz.

[3]

2.2 What does the bilinear transform do to the analog point $s = \sigma + j0$ with $\sigma < 0$? [3]

2.3 A digital filter has poles at $z = 0.9$ and $z = 0.5$. Stable? Why? [3]

3 Exam-style questions

3.1 Design a 1st-order Butterworth low-pass at 1 kHz cutoff, $f_s = 8$ kHz, by bilinear transform.

Prewarp the cutoff. Apply the transform with the prewarped constant to $H(s) = 1/(s+1)$ (s normalised by ω_a), giving $H(z)$ as $b_0(1+z^{-1})/(1+a_1z^{-1})$. Verify the dc gain and state the response at the cutoff frequency. [8]

3.2 The naive substitution ($K = 1$, no prewarp) is used for a 100 Hz, $f_s = 1$ kHz 2nd-order Butterworth.

State where the -3 dB point lands and why. Compute the response the naive filter shows at 100 Hz. Explain in one sentence why the error is small at low cutoffs and fatal near Nyquist. [7]
