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Signals and Systems Interview Questions

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Signals

1. How do you tell an energy signal from a power signal?

An energy signal has finite total energy and zero average power. A power signal has finite, nonzero average power and infinite energy. A decaying pulse such as $e^{-t}u(t)$ is an energy signal, and a periodic signal is a power signal. Some signals, like a ramp, are neither.

2. Why does $\delta(at)$ equal $\delta(t)/|a|$ and not simply $\delta(t)$?

The impulse is defined by its unit area. Substituting $\tau = at$ in $\int \delta(at)\,dt$ gives an area of $1/|a|$, so $\delta(at)$ must be $\delta(t)/|a|$. The modulus appears because area stays positive even when a is negative, which only reverses time.

3. A voltage $3\cos(100t) + 4\sin(100t)$ volts is applied across a $1\ \Omega$ resistor. Find the average power.

The average power is 12.5 W. Both terms have the same frequency, so they merge into one sinusoid of amplitude 5 V, and its power is $A^2/2$ across $1\ \Omega$.

WORKING

1. Same frequency, so merge the terms: $A = \sqrt{3^2 + 4^2} = 5$ V
2. Average power of a sinusoid across $1\ \Omega$: $P = A^2/2$
3. $P = 25/2 = 12.5$ W

LTI systems

4. What is the difference between a causal LTI system and a stable LTI system, in terms of the impulse response?

A causal system has $h[n] = 0$ for $n < 0$, so the output depends only on present and past inputs. A BIBO stable system has an absolutely summable $h[n]$, so every bounded input gives a bounded output. A system can be causal and still unstable, for example an accumulator.

5. Why does the impulse response describe an LTI system completely?

Any input can be written as a weighted sum of shifted impulses. Linearity lets the output be the same weighted sum of the responses to each impulse, and time invariance makes each of those responses a shifted copy of h. That sum is the convolution $x * h$.

6. A discrete-time LTI system has impulse response $h[n] = \delta[n] + 2\delta[n-1]$. The input is $x[n] = 1$ for $n = 0, 1, 2$ and zero elsewhere. Find the output sample $y[2]$.

The output sample $y[2]$ is 3. In the convolution sum $y[2] = \sum_k x[k]\,h[2-k]$, only $h[0] = 1$ and $h[1] = 2$ are non-zero, so the sum keeps two terms, each with an input sample of 1, giving $1 + 2 = 3$.

WORKING

1. $y[n] = \sum_k x[k]\,h[n-k]$
2. $y[2] = x[2]h[0] + x[1]h[1] + x[0]h[2]$
3. $y[2] = (1)(1) + (1)(2) + (1)(0) = 3$

Fourier series

7. What can symmetry of a periodic waveform tell you about its Fourier series without integrating?

An even waveform has only cosine terms, and an odd waveform has only sine terms. A waveform with half-wave symmetry, where $x(t + T/2) = -x(t)$, has only odd harmonics and no DC term. Each of these removes whole sets of coefficients before any integral is done.

8. Why does the Fourier series of a square wave overshoot near each jump, however many terms are used?

This is the Gibbs phenomenon. Partial sums of a signal with a jump converge to it away from the jump, but near it they overshoot by about 9% of the jump height. Adding terms makes the overshoot narrower, not smaller.

9. A square wave swings between $+2$ V and -2 V with 50% duty cycle and zero mean. Find the amplitude of its fundamental component.

The fundamental has amplitude about 2.55 V. For a square wave of amplitude A with odd half-wave symmetry, the sine coefficients are $4A/(n\pi)$ for odd n.

> **WORKING**
>
> 1. Only odd harmonics are present, as sine terms: $b_n = 4A/(n\pi)$
> 2. For the fundamental, $n = 1$ and $A = 2$ V
> 3. $b_1 = 8/\pi \approx 2.55$ V

Fourier transform, frequency response, group and phase delay

10. What is the difference between phase delay and group delay of a system?

Phase delay is $-\phi(\omega)/\omega$ and is the delay of a single sinusoid, so it applies to the carrier. Group delay is $-d\phi/d\omega$ and is the delay of the envelope of a narrowband signal. Distortionless transmission needs constant magnitude and a phase linear in ω through the origin, which makes both delays equal and constant.

11. Why does shortening a pulse in time widen its spectrum?

The scaling property says $x(at) \leftrightarrow \frac{1}{|a|}X(j\omega/a)$. Compressing the signal in time by $a > 1$ stretches its spectrum by the same factor. The product of duration and bandwidth stays roughly fixed, so a very short pulse needs a wide band.

12. What does Parseval's theorem state for the Fourier transform?

The energy of a signal can be found in either domain: $\int |x(t)|^2\,dt = \frac{1}{2\pi}\int |X(j\omega)|^2\,d\omega$. So $|X(j\omega)|^2$ is the energy spectral density in rad/s. It applies to energy signals, and it lets you find energy without finding $x(t)$.

Laplace transform, poles, zeros and system functions

13. Why must the region of convergence be stated along with a Laplace transform?

One algebraic $X(s)$ can belong to different time signals, and the ROC picks which. For $1/(s+1)$, the ROC $\mathrm{Re}(s) > -1$ gives $e^{-t}u(t)$, while $\mathrm{Re}(s) < -1$ gives $-e^{-t}u(-t)$. Without the ROC the inverse transform is

ambiguous.

14. How are causality and stability of $H(s)$ read from its poles and ROC?

A causal system has an ROC to the right of its rightmost pole. A stable system has an ROC that contains the $j\omega$ axis. A system that is both causal and stable therefore has all poles in the open left half of the s-plane.

15. Why is the unilateral Laplace transform used to solve differential equations with initial conditions?

Its derivative property is $\mathcal{L}\{dx/dt\} = sX(s) - x(0^-)$. The initial values enter the algebra automatically, so the response to both input and initial conditions comes out in one step. The solution is then recovered by partial fractions and the inverse transform.

Sampling and reconstruction

16. What does the sampling theorem say, and what is the Nyquist rate?

A signal bandlimited to f_m can be rebuilt from its samples if the sampling rate satisfies $f_s > 2f_m$. The Nyquist rate is $2f_m$. Sampling repeats the spectrum at multiples of f_s, and the copies stay apart only above this rate, so an ideal lowpass filter can recover the original.

17. A 7 kHz sinusoid is sampled at 10 kHz and the samples pass through an ideal lowpass reconstruction filter with a 5 kHz cutoff. What frequency does the output contain?

The output is a 3 kHz tone. The 7 kHz tone is above half the sampling rate, so it aliases to the nearest image inside the band.

> **WORKING**
>
> 1. Half the sampling rate is $f_s/2 = 5$ kHz, and 7 kHz is above it
> 2. Apparent frequency $f_a = |f - kf_s|$ with k the nearest integer
> 3. $f_a = |7 - 10| = 3$ kHz

18. Why is an analog anti-aliasing filter placed before a sampler?

Components above $f_s/2$ fold into the band of interest during sampling, and after sampling they look like genuine lower frequencies, so no digital step can separate them. A lowpass filter before the sampler removes them first. It must roll off before $f_s/2$.

z-transform and discrete-time systems

19. How are causality and stability of $H(z)$ read from its poles and ROC?

A causal system has an ROC outside its outermost pole. A stable system has an ROC that contains the unit circle. A causal, stable system therefore has all its poles strictly inside the unit circle.

20. A causal system has $H(z) = \dfrac{1}{1 - 0.8z^{-1}}$. Find the magnitude of its frequency response at $\omega = 0$.

The magnitude at $\omega = 0$ is 5. The pole at 0.8 is inside the unit circle, so the unit circle is in the ROC and the frequency response exists.

WORKING

1. The frequency response is $H(z)$ on the unit circle, $z = e^{j\omega}$
2. At $\omega = 0$, $z = 1$
3. $H(1) = 1/(1 - 0.8) = 5$

DTFT, DFT and FFT

21. What is the difference between the DTFT and the DFT?

The DTFT of a sequence is a continuous function of ω that repeats every 2π. The DFT of an N-point block is N equally spaced samples of that DTFT, at $\omega = 2\pi k/N$. The DFT is what a computer can calculate, and it is periodic in both domains.

22. How many complex multiplications does a 1024-point radix-2 FFT need?

It needs 5120 complex multiplications. A radix-2 FFT of N points uses $(N/2)\log_2 N$ of them, here 512×10. Direct evaluation of the DFT would need N^2, which is over a million.

WORKING

1. A radix-2 FFT of size N uses $(N/2)\log_2 N$ complex multiplications
2. $N = 1024$, so $\log_2 N = 10$
3. $(1024/2)(10) = 5120$

FIR and IIR filters

23. What is the difference between an FIR filter and an IIR filter?

An FIR filter has a finite impulse response, no feedback, is always stable and can have exactly linear phase. An IIR filter uses feedback and meets a magnitude specification with a much lower order. Its price is possible instability and nonlinear phase.

24. Why is prewarping needed in the bilinear transformation?

The bilinear transformation maps the whole analog frequency axis onto the unit circle, which avoids aliasing, but it does so nonlinearly: $\omega = 2\tan^{-1}(\Omega T/2)$. The band edges would land at the wrong digital frequencies. Prewarping with $\Omega = (2/T)\tan(\omega/2)$ puts the critical frequencies in the right place.

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