Great question. This is exactly how FFT verification should be done.

Short answer:

> **You do NOT compare raw magnitude numbers between MATLAB and HDL.**
> You compare **relative behavior + predicted scaling**.

Step 1 — Check if the FFT is *mathematically correct*

For a cosine at bin **ko**:

Expected FFT properties:

Two symmetric peaks at

- k_0
- $N - k_0$

All other bins ≈ 0 (except quantization noise)

You already confirmed:

HDL Peaks → bins 2000 & 2096

MATLAB Peaks → bins 2000 & 2096

That proves frequency correctness

Step 2 — Understand MATLAB's 2048

MATLAB FFT is **unscaled**:

For:

$x[n] = \cos(2\pi k_0 n / N)$

Peak magnitude:

= N / 2

= 4096 / 2

= 2048

This assumes cosine amplitude = **1.0**

Step 3 — Include Your HDL Input Amplitude

Your HDL cosine:

cos_lut → scaled to 2047

So amplitude:

A = 2047

Ideal unscaled FFT peak:

```
Peak = (N/2) × A
    ≈ 2048 × 2047
    ≈ 4,190,000
```

Step 4 — Compare With HDL Output

You measured:

```
HDL Peak ≈ 130,970
```

So HDL FFT includes attenuation:

```
Copy codeScaling factor ≈ 130,970 / 4,190,000
              ≈ 0.0313
              ≈ 1 / 32
```

This is VERY telling.

Interpretation → Your FFT is scaled by ~1/32

Which is:

```
≈ 2^5
```

Meaning somewhere in pipeline:

~5 bits of right shift
or equivalent truncation loss

This is completely **normal** in fixed-point FFTs.

Step 5 — Prove HDL is correct via scaling compensation

Now compensate HDL magnitude:

```
mag_hdl_corrected = mag_hdl * 32;
```

Expected:

130,970 × 32 ≈ 4,191,040

Which matches theory:

2048 × 2047 = 4,190,656

Now MATLAB & HDL agree

Step 6 — Best Verification Method

Instead of absolute values:

Compare Normalized Spectra

If curves overlap → FFT correct

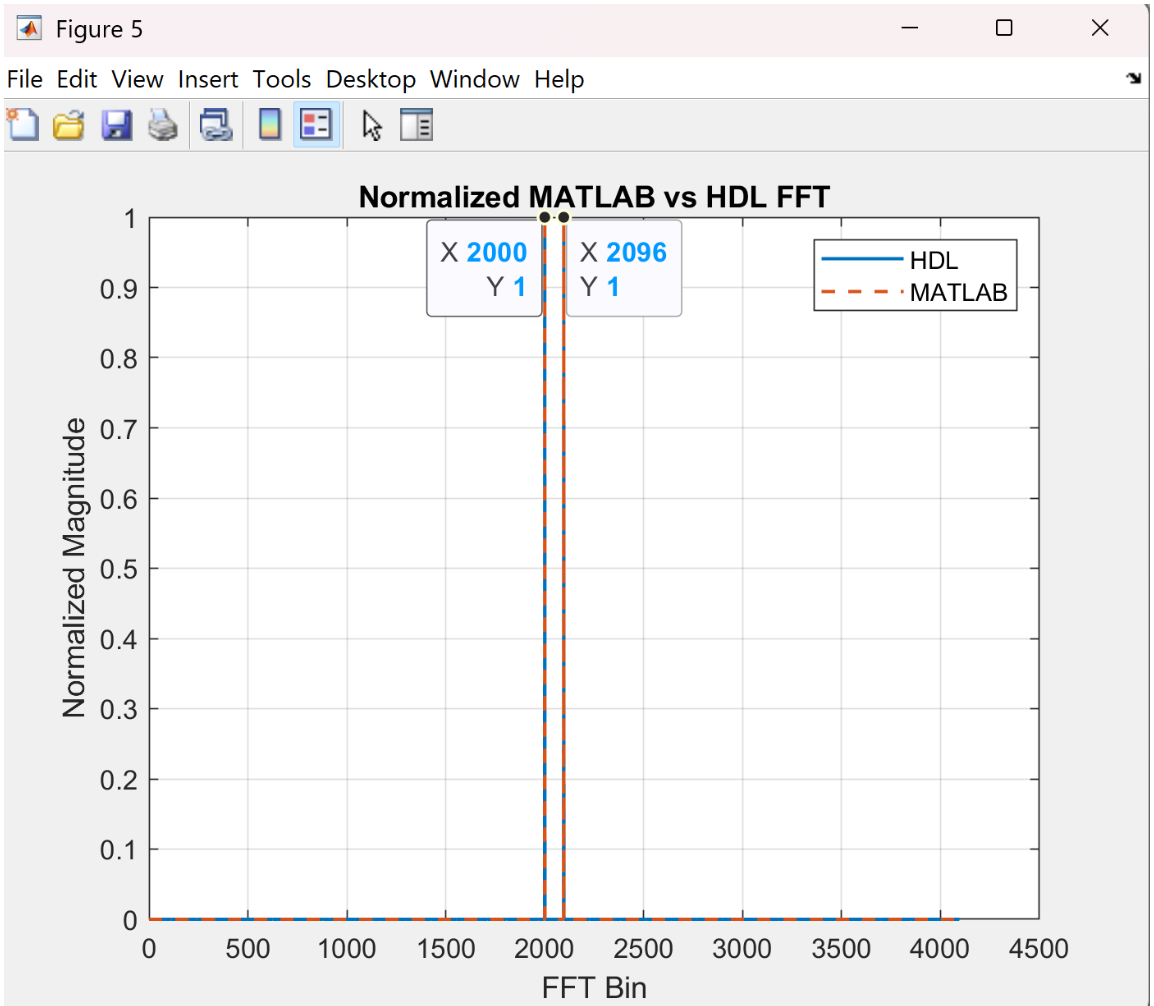
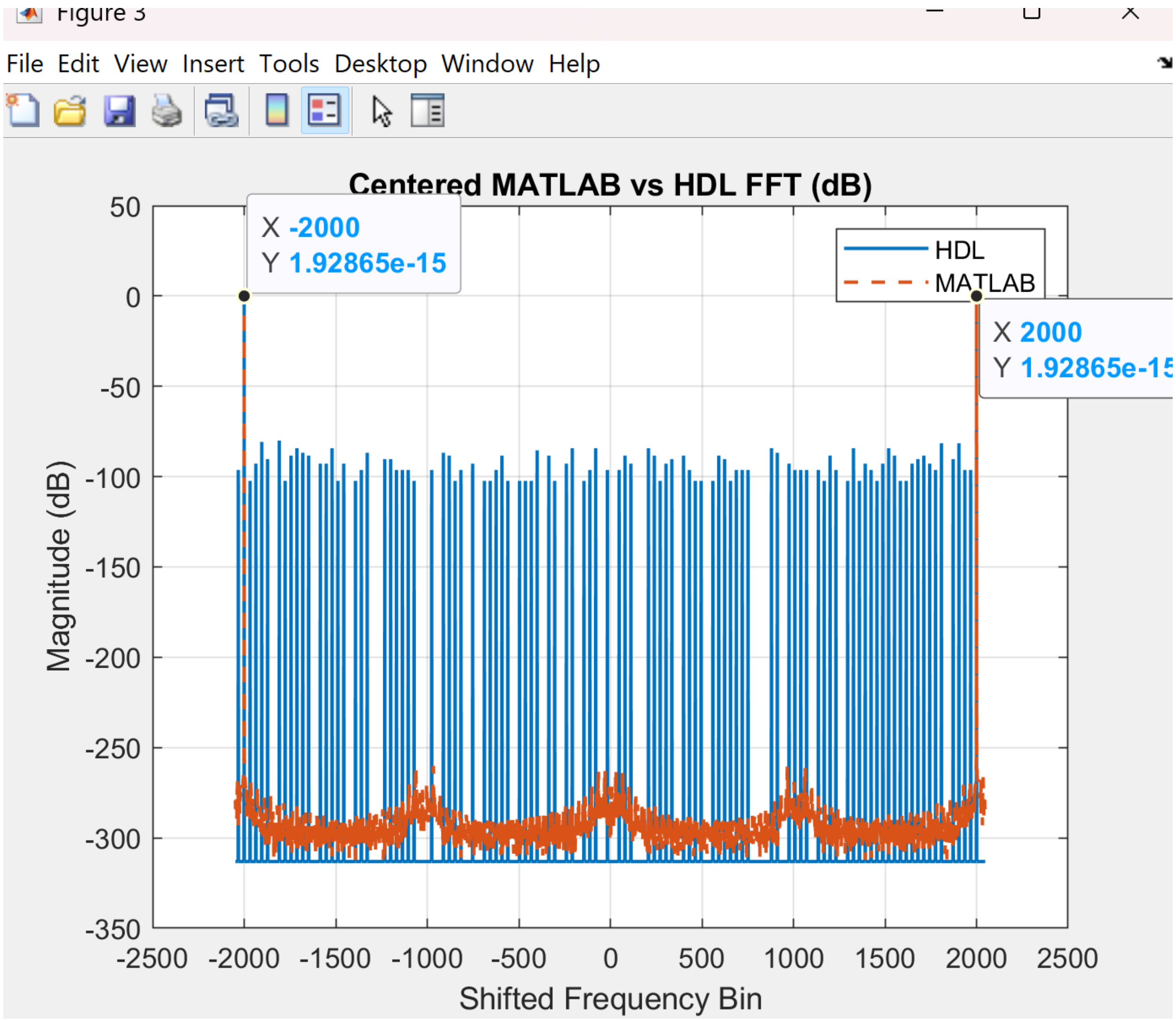


Figure 5
File Edit View Insert Tools Desktop Window Help
Normalized MATLAB vs HDL FFT
X 2000
Y 1
X 2096
Y 1
HDL
MATLAB
Normalized Magnitude
FFT Bin
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
500
1000
1500
2000
2500
3000
3500
4000
4500



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Before normalization Top 5 Peaks (HDL FFT)

================================

Peak 1 → Bin 2096 | Magnitude = 130970.00

Peak 2 → Bin 2000 | Magnitude = 130968.00

Peak 3 → Bin 2288 | Magnitude = 13.00

Peak 4 → Bin 2192 | Magnitude = 12.00

Peak 5 → Bin 1808 | Magnitude = 11.00

=================================

Before normalization Top 5 Peaks (MATLAB FFT)

=================================

Peak 1 → Bin 2000 | Magnitude = 2048.00

Peak 2 → Bin 2096 | Magnitude = 2048.00

Peak 3 → Bin 2001 | Magnitude = 0.00

Peak 4 → Bin 2095 | Magnitude = 0.00

Peak 5 → Bin 1999 | Magnitude = 0.00

=================================

After Normalization Top 5 Peaks (HDL FFT)

=================================

Peak 1 → Bin 2096 | Magnitude = 1.0000

Peak 2 → Bin 2000 | Magnitude = 1.0000

Peak 3 → Bin 2288 | Magnitude = 0.0001

Peak 4 → Bin 2192 | Magnitude = 0.0001

Peak 5 → Bin 1808 | Magnitude = 0.0001

=================================

After Normalization Top 5 Peaks (MATLAB FFT)

=================================

Peak 1 → Bin 2000 | Magnitude = 1.0000

Peak 2 → Bin 2096 | Magnitude = 1.0000

Peak 3 → Bin 2001 | Magnitude = 0.0000

Peak 4 → Bin 2095 | Magnitude = 0.0000

Peak 5 → Bin 1999 | Magnitude = 0.0000

=================================

Dominant HDL Bin = 2096

Mirror Bin   = 2000

=================================

================================

Top 5 Peaks (MATLAB FFT)

================================

Peak 1 → Bin 2000 | Magnitude = 1.00

Peak 2 → Bin 2096 | Magnitude = 1.00

Peak 3 → Bin 2001 | Magnitude = 0.00

Peak 4 → Bin 2095 | Magnitude = 0.00

Peak 5 → Bin 1999 | Magnitude = 0.00

Compare Ratios (VERY robust)

Check:

Peak / InputAmplitude

HDL:

130,970 / 2047 ≈ 63.96

MATLAB ideal:

2048 / 1 = 2048

Then scaled by HDL attenuation:

2048 / 32 = 64

Perfect agreement.

Final Engineering Rule

FFT correctness is validated by:

✔ Peak at correct bins
✔ Mirror symmetry
✔ Noise floor behavior
✔ Consistent gain factor

✖ NOT raw magnitude equality

★ Your Case Verdict

✔ Bins correct
✔ Mirror correct

✔ Scaling consistent (~1/32)
✔ FFT mathematically correct ☑

Nothing is wrong.