Mental Model: Digital Signal Processing: Time ↔ Frequency Reality

🔷 1. Time Domain = Where the Work Happens

- **Everything is stored and manipulated as sequences of numbers**: $x[n], h[n], y[n]$
- You apply filters, convolution, algorithms, etc. **in time domain**
- **Mathematical operations like `lfilter`, `convolve`, etc.** work directly on samples
- All code, hardware, and real-time systems process signal **sample by sample**, or block-by-block

> 💡 Time domain is the "hands-on workspace" of DSP.

🔷 2. Frequency Domain = Where You Analyze the Effect

- You switch to frequency domain (via FFT, DFT) to:
  - Understand what your signal is made of (spectrum)
  - Verify filter behavior (e.g., does it cut off 2 kHz as intended?)
  - Design or interpret filter responses
- **But you don't operate directly in frequency domain unless needed** (e.g., FFT filtering, spectral subtraction)

> 💡 Frequency domain is the "diagnostic lens" — you *see* the effect of what you did in time domain.

🔷 3. The Complete System (Tx–Rx)

Let's walk through what you hinted — a **real-world DSP path** from analog to digital and back:

📡 TRANSMISSION SIDE:

1. **Analog signal (microphone, antenna)**

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2. **ADC** → samples it to produce $x[n]$

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3. **Digital filtering / modulation / encoding (DSP)**

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4. **DAC** → converts it back to analog

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5. **Transmission** (RF, audio, etc.)

📶 RECEIVER SIDE:

1. **Analog input (antenna, sensor)**

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2. **ADC** → digitizes to $x[n]$

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3. **DSP applies filtering, detection, demodulation**

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4. **You extract information** (audio, video, IQ, data)

✅ Key Principles (What to Remember)

Concept	Role
Time Domain	Where DSP happens (convolution, filtering, modulation)
Frequency Domain	Where interpretation and filter design is verified
ADC	Converts real-world signal → digital samples
DSP	Processes those samples using mathematical operations
DAC	Converts processed digital samples → analog signal

🛞 Real-World Analogy:

Stage	Analogy
Time domain filtering	Cooking: you follow a recipe (weighted steps on samples)
Frequency domain	Nutrition label: shows how healthy the output is (what's inside)
ADC/DAC	Converts between **ingredients** (analog) and **numbers** (digital)