Lab - 4

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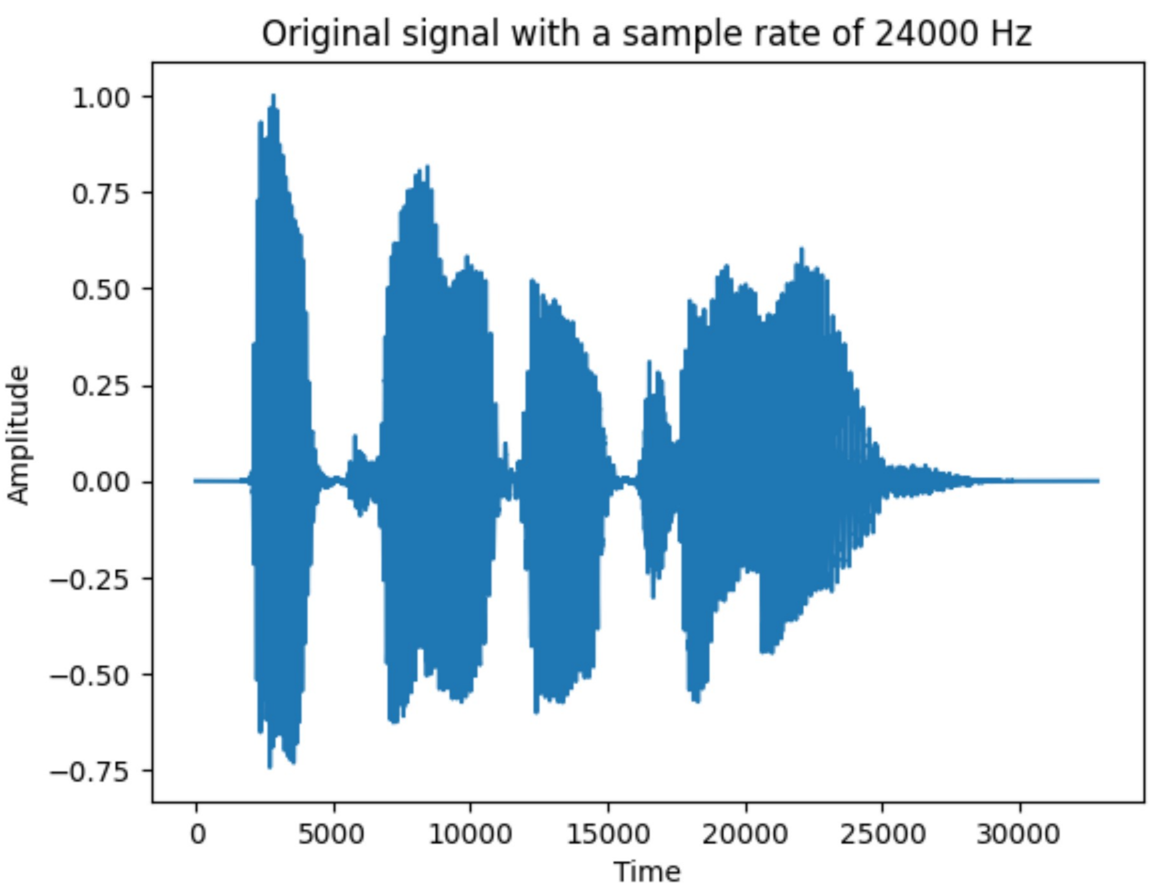
a) Use a recorded short speech signal/download the same from any speech dataset.

In [55]:
```
from scipy.io import wavfile
import matplotlib.pyplot as plt

sample_rate, speech = wavfile.read(r"C:\Users\purus\Downloads\tts_output_2.wav")
speech = speech / np.max(speech)
plt.plot(speech)
plt.title(f"Original signal with a sample rate of {sample_rate} Hz")
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.show()
```



The speech in the above signal is **Okay, that's enough**.

b) Implement the LPC algorithm to analyze the recorded speech signal and extract LPC coefficients.

We will follow the following approach,

- Calculate the autocorrelation
- Use the autocorrelation to create the Toeplitz matrix
- Solve the matrix for the LPC coefficients

In [59]:
```
import numpy as np
from scipy.linalg import toeplitz

def lpc(signal, order):
    # Autocorrelation
    autocorr = np.correlate(signal, signal,
                            mode='full')
    autocorr = autocorr[len(autocorr)//2:]

    # Creating the Toeplitz matrix
    R = toeplitz(autocorr[:order])
    r = autocorr[1:order + 1]

    # Solving for LPC coefs
    lpc_coef = np.linalg.solve(R, r)

    return np.concatenate([[1], -lpc_coef])

lpc_coef = lpc(speech, 24)
lpc_coef
```

Out[59]:
```
array([ 1.        , -1.23437698,  0.39142068, -1.05406396,  1.46920811,
       -0.79030653,  0.87485074, -1.39309475,  1.15156552, -0.89864587,
        1.15199626, -1.15640097,  0.92521916, -0.94875708,  1.13872065,
       -0.94842295,  0.75340807, -0.93229446,  0.73323912, -0.43533597,
        0.56968847, -0.46728685,  0.19907055, -0.2763213 ,  0.20705446])
```

These coefficients capture the predictive relationship between the samples in the speech signal.

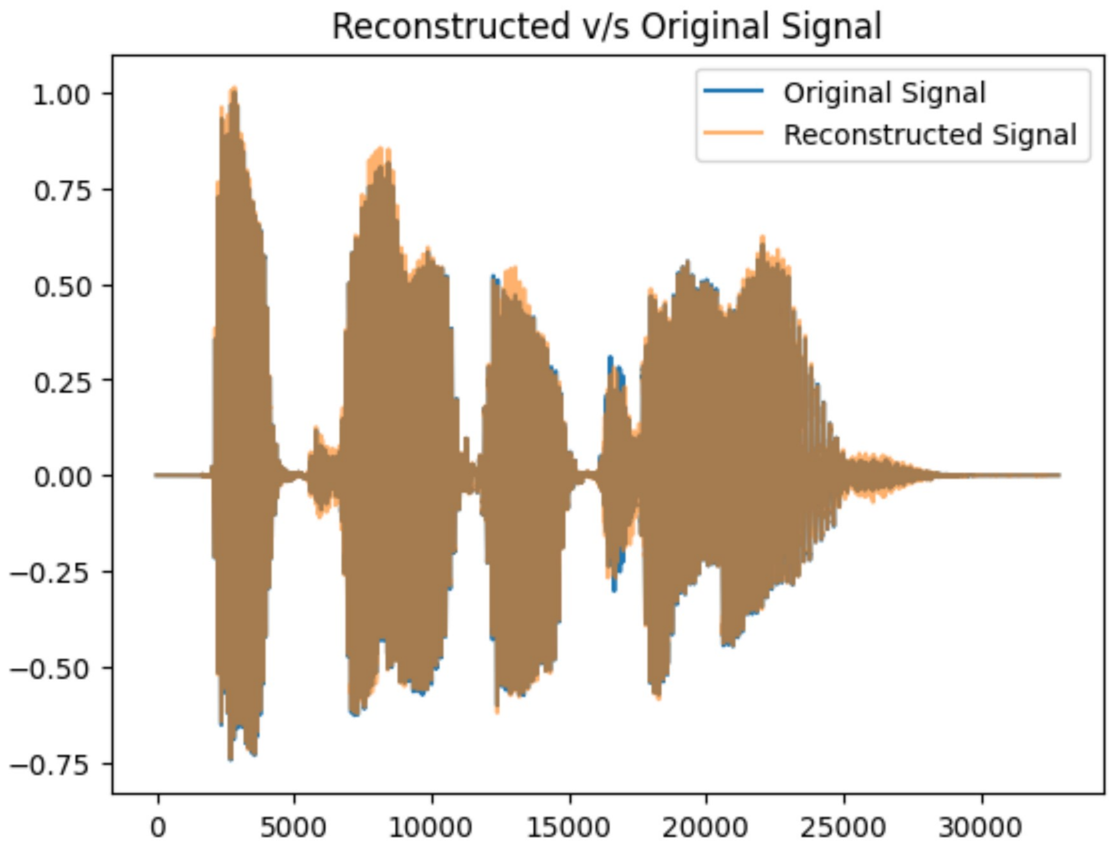
c) Reconstruct the speech signal from the LPC coefficients and plot the original and reconstructed signals.

We will use inverse filtering to reconstruct the signal.

In [65]:
```
from scipy.signal import lfilter

reconstructed = lfilter([0] + -lpc_coef[1:], [1], speech)

plt.plot(speech, label='Original Signal')
plt.plot(reconstructed, alpha=0.6, label='Reconstructed Signal')
plt.title("Reconstructed v/s Original Signal")
plt.legend()
plt.show()
```



d) Estimate the formants from the LPC coefficients and compare them to the expected values for vowels (e.g., for vowels like /a/, /e/, /i/, etc.).

e) Plot the formant frequencies and visualize them on a frequency response plot.

In [68]:
```
# Finding the roots of the LPC polynomial
roots = np.roots(lpc_coef)

# Filtering out the roots outside the unit circle
roots = [r for r in roots if np.abs(r) < 1]

# Calculating the angles of the roots
angles = np.angle(roots)

# Converting angles to frequncies
formants = sorted(angles * (sample_rate / (2 * np.pi)))

# Keeping only speech formants
formants = [f for f in formants if f > 100 and f < 4800]
formants
```

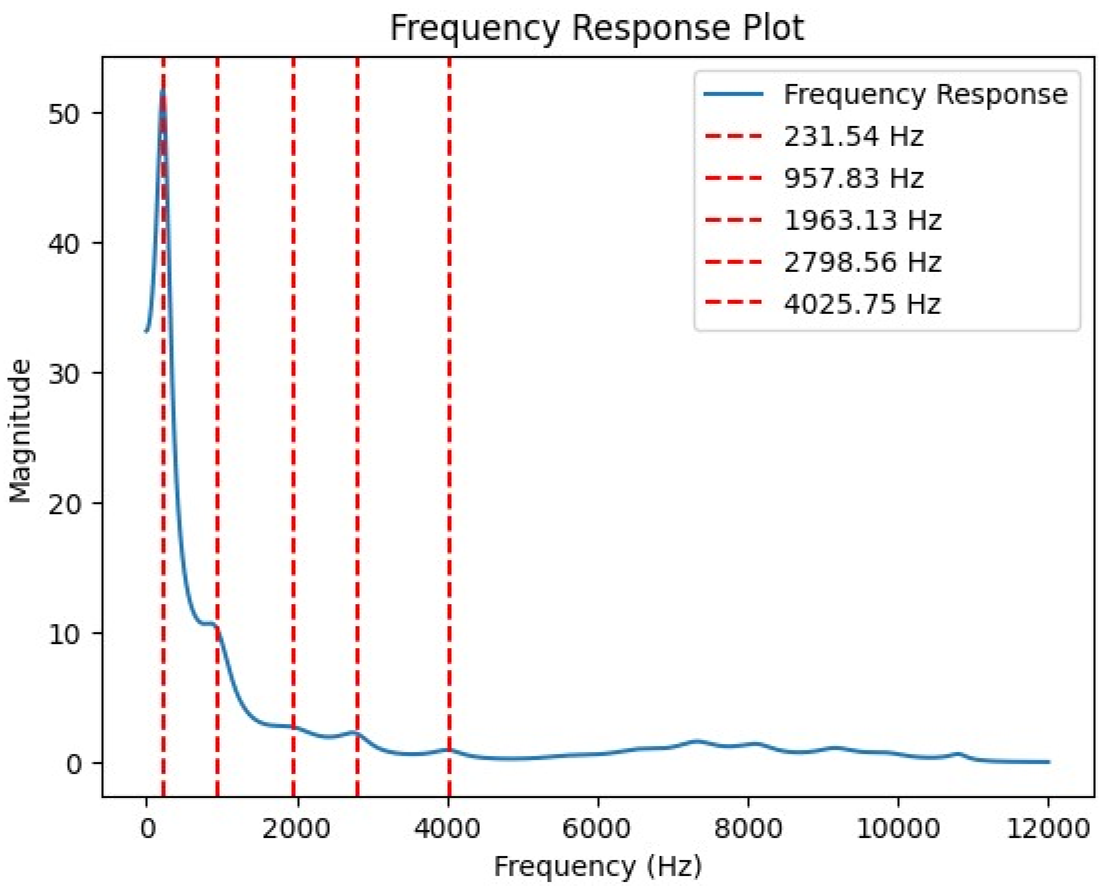
Out[68]:
```
[231.53565393821063,
 957.8340850861464,
 1963.131867014958,
 2798.559227254418,
 4025.7504735388766]
```

In [74]:
```
from scipy.signal import freqz

w, h = freqz(1, lpc_coef, worN=8000)
freqs = w * sample_rate / (2 * np.pi)
```

```python
plt.plot(freqs, np.abs(h), label='Frequency Response')
plt.title("Frequency Response Plot")
plt.xlabel("Frequency (Hz)")
plt.ylabel("Magnitude")

for formant in formants:
    plt.axvline(formant, color='red', linestyle='--', label=f'{formant:.2f} Hz')
plt.legend(loc='best')
plt.show()
print(f"Formants: {formants}")
```




```
Formants: [231.53565393821063, 957.8340850861464, 1963.131867014958, 2798.559227254418, 4025.7504
735388766]
```

Let us look at what the format frequencies represent in terms of vowels, Average vowel formants[7]

Vowel (IPA)	Formant f_1	Formant f_2
i	240 Hz	2400 Hz
y	235 Hz	2100 Hz
e	390 Hz	2300 Hz
ø	370 Hz	1900 Hz
ɛ	610 Hz	1900 Hz
œ	585 Hz	1710 Hz
a	850 Hz	1610 Hz
æ	820 Hz	1530 Hz
ɑ	750 Hz	940 Hz
ɒ	700 Hz	760 Hz
ʌ	600 Hz	1170 Hz
ɔ	500 Hz	700 Hz
ɤ	460 Hz	1310 Hz
o	360 Hz	640 Hz
ɯ	300 Hz	1390 Hz
u	250 Hz	595 Hz

Figure 1. IPA: International Phonetic Alphabet

Therefore, we have,

```
231 Hz - /y/, /i/, /u/
957 Hz - /a/
1963 Hz - either /e/ or /o/
```

The initial sentence was **Okay, that's enough**, so the vowels, /a/, /e/, /o/, and /u/ are present.

End