Fourier Transform Application: Antenna Impedance

Corbett Rowell

Abstract—This paper discusses the application of Fourier Transforms for determining antenna and RF performance within an electromagnetic simulator such as FDTD (Finite Difference Time Domain). Using the Fourier Transform, we can calculate the complex impedance in order to determine the resonance frequency, input impedance.

Index Terms—impedance, fourier, s-parameters, FDTD

I. INTRODUCTION

The Fourier transform is used for transforming the time domain voltage and current signals into the frequency domain for calculating the input impedance. The voltage and current signals may be obtained from an electromagnetic field simulator, such as FDTD, or experimentally by exciting the device with a Gaussian pulse. By graphing the Real and Imaginary parts of the input impedance, the resonant frequencies of the antenna/RF device can be determined. With further processing, the antenna bandwidth can also be calculated.

II. METHODOLOGY

A voltage source \( v(t) \) is placed within an EM simulator (or a voltage source is used in an network analyzer with the DUT attached via cable). The transient current response \( i(t) \) is then measured either within the EM simulator or the network analyzer. After obtaining, measuring the time domain signals, the Fourier transform is used to calculate the frequency response of the system to determine resonant frequency:

\[
I(f) = \int i(t)e^{-2\pi jft} dt
\]

\[
V(f) = \int v(t)e^{-2\pi jft} dt
\]

The \( dt \) is set by the instrument/FDTD program with a typical value of nanoseconds. The corresponding frequency interval \( df \) can be calculated by: \( df = \frac{1}{m \cdot \text{spacing}} \); where \( m \) =number of samples. The input impedance is a measure of how much power gets reflected from the load. The load can be an antenna or another RF circuit. The impedance (complex) is defined as:

\[
Z = \frac{V}{I} = \frac{\int v(t)e^{-2\pi jft} dt}{\int i(t)e^{-2\pi jft} dt}
\]

By graphing \( Z(f) \), we can determine the resonant frequencies of the antenna and the ideal matching impedance for the microstrip line. When the \( \text{Im}(Z) \) crosses zero, then this is the point of maximum power transfer with no reflections. The canonical dipole antenna’s first resonance can be shown to be \( \lambda/2 \) with a input impedance of 777\( \Omega \). Most microstrip lines have a \( \text{Re}(Z) = 50\Omega \), so if the antenna has a different impedance \( \text{Re}(Z) \), then a matching circuit will be required to transform the antenna impedance to the microstrip line impedance.

III. RESULTS

In this paper, we use the canonical dipole for demonstrating the application of the Fourier transform to determine resonant frequencies and input impedance. In the FDTD simulation, the dipole length is set to 30 cm. The theoretical resonant frequency can be calculated from the following equation: \( f = \frac{c}{\lambda} = 1000MHz \). The input voltage signal is defined as a Gaussian pulse where \( \beta \) sets the pulse width to cover a targeted frequency band (dependent on the material–air, dielectric, etc and is typically set at 256 to cover 500 MHz to 3 GHz), \( \tau \) is the time delay of the pulse, and \( \alpha \) sets the source value at pulse truncation:

\[
v_{\text{source}} = -2\alpha(\tau - \beta \Delta t)\Delta t e^{-\alpha(\tau - \beta \Delta t)^2}
\]

The FDTD simulator determines the output current at the source (transient signal response). Figure 1 shows the time domain voltage and current signals and the Fourier Transform. From Figure 1b, the resonant frequency is 900 MHz with an impedance of 80\( \Omega \). This is different from the theoretical calculations by 10% for the resonant frequency and 3% for the impedance. This is due to the EM simulator errors (grid spacing, electric and magnetic field offsets, wave propagation, boundary effects) and the simulator assumed a dipole of finite width.

IV. CONCLUSIONS

The resulting calculations demonstrate that a dipole is best matched with a 80\( \Omega \)load. Therefore, in order to obtain a perfect match within the RF circuit, a matching circuit must be used. In addition, the frequency response shows the dipole has many resonant frequencies with different impedances (though for practical use, only the first and the third are used since the second resonance has a very high impedance (1000 + \( \Omega \)). In conclusion the Fourier Transform can be used in time domain measurements in order to determine the frequency response of any antenna or RF circuit.