# **Broadband SRR Stack Design for All Frequencies: −∞−∞ to +∞+∞ Hz**

## **1. Introduction**

Split-ring resonators (SSR) are artificially constructed electromagnetic structures designed to exhibit specific resonance frequencies. When organized in layers, they can influence and manipulate electromagnetic waves in unprecedented ways. For an effective broadband SSR stack covering the entire frequency spectrum, it's crucial to understand the dynamics between the overlays of gold and silver rings within each SSR.

## **2. Transfer Function of the Metamaterial**

The transfer function in the frequency domain is represented as:

H(f)=∏i=1N11−jπfτiH(f)=∏i=1N​1−jπfτi​1​

In the Laplace domain, considering each layer has its own transfer function, it's given by:

H(s)=H1(s)×H2(s)×...×Hn(s)H(s)=H1​(s)×H2​(s)×...×Hn​(s)

Where:

* H(f)H(f) and H(s)H(s) are the transfer functions of the metamaterial in the frequency and Laplace domains, respectively.
* ff is the frequency in THz.
* NN and nn are the number of layers in the metamaterial.
* τiτi​ represents the time delay of the ithith layer.

### **Understanding the LaTeX Symbols:**

* H(f)H(f) and H(s)H(s): These denote the transfer functions of the metamaterial. The ff and ss within the parentheses indicate that the function is in terms of frequency and Laplace transform variable, respectively.
* ∏i=1N∏i=1N​: Signifies the product of all terms from i=1i=1 to i=Ni=N. Specifically, the terms are the fractions 11−jπfτi1−jπfτi​1​.
* 11−jπfτi1−jπfτi​1​: Denotes the transfer function for an individual layer of the SRR stack. Here, jj is the imaginary unit, ππ is pi, ff is the frequency in THz, and τiτi​ is the time delay of the ithith layer.

## **3. Time Delay Calculation**

A pivotal element in computing the transfer function is the determination of the time delay for each layer, denoted as τiτi​. The formula to ascertain this delay is:

τi=hicτi​=chi​​

Where:

* τiτi​ is the time delay of the ithith layer.
* hihi​ represents the thickness of the ithith dielectric layer.
* cc is the speed of light.

## **4. Designing the SSR and Compacting the Stack**

### **4.1 Designing the SSR:**

For each frequency:

1. Design an SSR with the given ring diameter, ring thickness, and dielectric layer thickness.
2. Ensure that the gold and silver rings overlap in the center.
3. Position the dielectric layer between the gold and silver rings.

### **4.2 Compacting the SSR Stack:**

1. Overlap the silver ring of one SSR with the gold ring of the adjacent SSR.
2. Alternatively, overlap the gold ring of one SSR with the silver ring of the next.

### **4.3 Frequency Design Table:**

| **Frequency (THz)** | **Ring diameter (nm)** | **Ring thickness (nm)** | **Dielectric layer thickness (nm)** | **Gold ring overlap** | **Silver ring overlap** |
| --- | --- | --- | --- | --- | --- |
| −∞−∞ | - | - | - | - | - |
| 400 | 100 | 10 | 75 | Yes | Yes |
| 450 | 90 | 10 | 70 | No | Yes |
| 500 | 80 | 10 | 65 | Yes | No |
| 550 | 70 | 10 | 60 | No | Yes |
| 600 | 60 | 10 | 55 | Yes | No |
| 650 | 50 | 10 | 50 | No | Yes |
| 700 | 40 | 10 | 45 | Yes | No |
| 750 | 30 | 10 | 40 | No | Yes |
| 780 | 20 | 10 | 35 | Yes | No |
| +∞+∞ | - | - | - | - | - |

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## **5. Bode Plots and the Human Eye**

### **5.1 Bode Plots**

A Bode plot is a graphical representation of a linear time-invariant system's transfer function. There are two separate plots in a Bode diagram:

1. **Magnitude Plot**: Represents the magnitude (in dB) of the transfer function versus frequency.
2. **Phase Plot**: Illustrates the phase angle (in degrees) of the transfer function versus frequency.

For the SSR stack, Bode plots can give a clear view of how each layer and the overall system responds to different frequencies.

### **5.2 Voltage and Electron Volts (eV) in the Human Eye**

When it comes to the human eye's interaction with light, understanding energy levels becomes crucial. The energy of a photon (a light particle) can be represented in electron volts (eV). This value is directly proportional to the photon's frequency and inversely proportional to its wavelength.

The human eye is sensitive to a range of wavelengths from approximately 390 to 700 nm, which corresponds to energy levels from about 1.77 eV (red light) to 3.26 eV (violet light). The cells in our eyes, known as photoreceptors, generate a voltage response when they absorb photons. This response, through a complex chain of reactions, leads to the generation of an electrical signal sent to the brain.

Different colors in the visible spectrum will induce different energy levels in the photoreceptors. The relationship between the energy (in eV) and the frequency (in Hz) of light is given by the equation:

E=h×fE=h×f

Where:

* EE is the energy in eV.
* hh is the Planck's constant (approximately 4.135667696x10−154.135667696x10−15 eV·s).
* ff is the frequency in Hz.

By understanding these energy levels and how the eye responds, we can better design metamaterials and devices to interact with or manipulate human vision.

## **6. Conclusion**

Constructing an effective broadband SSR stack encompasses intricate design, understanding of metamaterials, and mathematical modeling through transfer functions and Bode plots. Recognizing the nuances of how the human eye interacts with various light frequencies further enriches our approach to such designs.