Antenna Tuning Circuit

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Abstract:
The purpose of this white paper is to introduce the concept of antenna tuning circuit or antenna matching circuit to integrate the antenna to the receiver network to obtain the optimum insertion loss. In the present technology state, this tuning principal is achieved using a component tuning circuit (T-Network circuit) with individual capacitors and inductor network to match the antenna to the receiver circuit. In this white paper we propose a tuning circuit to replace the T-Network circuit which allows for the self tuning of the antenna to the receiver. The self tuning is performed by varying a voltage source in the tuning circuit. The circuit matches the capacitive, inductive, and resistive load of the antenna to the receiver chain. The tuning circuit will allow engineers to reduce the overall foot print of the printed circuit board design, the component counts, and reducing the overall cost of the receiver/transmitter PCB(printed circuit board) design.

Introduction:
Antennas are widely used across multiple industries in the field of telecommunication ranging from consumer products such as personal cellphones, to industrial products in transportation, entertainment, and law enforcement, and to closed loop military systems. Furthermore, the rapid development of the personal computer industry, a stratification of technologies in the field of telecommunication technologies demands integration of a single compact circuit to accommodate the need for the consumer industries. The antennas performance greatly varies in each industry due to the requirements of the industry. As a results, chip antenna matching and radiation pattern performance can be dramatically affected by the design/layout of the circuit. In antenna mounting, the antenna's position relative to circuit, mismatches occur with the antennas impedance and parasitic relative to adjacent components and ground planes, all of which can affect antenna performance. Thus, design engineers must use care when creating a circuit layout which includes an antenna.

Tuning the antenna is another concern in optimizing the performance of the receiver/transmitter circuit. The tuning is often performed utilizing a T-network to properly match the antenna's characteristics to the RF receiver. A T-network consists of two capacitors and an inductor connected to GND with the junction of the capacitors connected to the inductor (refer to figure 1).

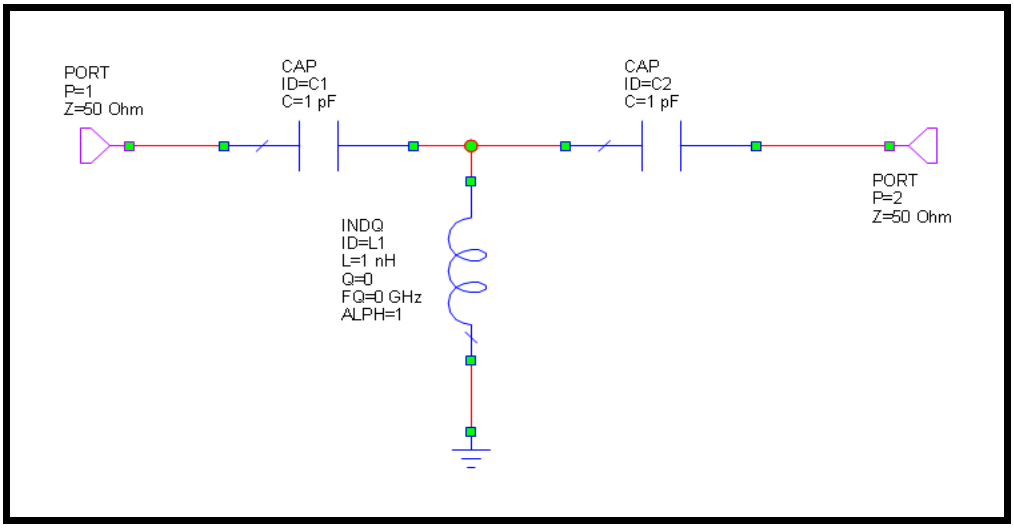

Figure 1: Schematic Representation of a T-Network.

The T-network often comes at the cost of added component counts which increases the cost of the printed circuit board, a larger layout footprint, and tuning required to optimize the network. At DS Scientific, we have developed a single chip circuit which can match the antenna's characteristics to the RF receiver utilizing a single voltage control to reduce the development cost and the time to market of the commercial product. The design offers many advantages over existing telecommunication systems for the commercial and military markets by reducing the component counts to a single component with a reduced PCB footprint. The tuning is performed through a single voltage supply. This white paper discusses the performance of the tuning chip.

Summary:

The T-network is a versatile matching circuit. By adjusting the capacitors and inductor values, the T-network can match any antenna impedance that you are likely to encounter to the receiver. Impedance matching using a passive network is very important in the design of RF and microwave circuits to achieve maximum power transfer, minimum reflection, and adequate harmonic rejection. By matching the load impedance to the complex conjugate of the source impedance the load can obtain maximum power from the source. When a transmission line is used to transfer power to the load the wave power is completely absorbed by the load and reflection is minimized by matching the impedance of the load to the characteristic impedance of the transmission line. This overall process becomes very costly and time consuming since there could be an infinite number of possible capacitor and inductor values that could achieve a proper match.

In practical application, the values of the passive components (such as inductors and capacitors) in impedance matching networks often deviate from the theory design value influenced by nominal value tolerances, parasitic, and manufacturing process variations. For example, capacitance can vary up to ±20% for a metal–insulator–metal capacitor due to process variation. These component deviations can cause the impedance matching networks to deviate from perfect matches. In addition to component deviation, variation of load impedance and working frequency drift in applications, such as cell phone antenna, can also cause deviation from perfect matches.

DS Scientific's solution to the issue is the tuning circuit which allows the customer to adjust and account for the variations in parasitic through a voltage source. A dual band antenna was designed in order to test the matching characteristics of the tuning circuit. Due to the rapid development in the telecommunication industry, a single antenna design is required to cover the widest possible set of frequencies. Some of the techniques proposed for multi-band antenna designs include planar monopoles similar to the antenna presented in this white paper, where multiple-mode operations are obtained by modifying the radiators so that multiple current paths are formed. This requires large antenna sizes. Designing a small antenna to operate in several frequency bands is formidably challenging because of the difficulties in impedance matching and volume reduction. Tunable antenna is one of the ways to overcome such problems. Recently tunable antennas have been studied on different types of antenna such as patch antennas, loop antennas, and Planar-Inverted-F antennas (PIFA). The antenna utilized in the design is a dual micro-strip line for the radiant elements which creates a resonance set at 2.2GHz and 3.5GHz (refer to figure 2).

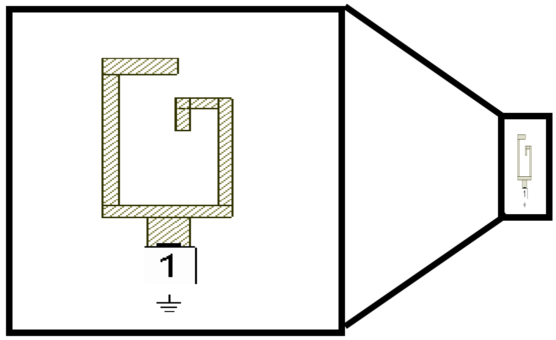

Figure2: Dual Band Antenna Design with Actual Size Shown On The Right.

The antenna is designed on a substrate with the relative permitivity (ε_r) of 3.5, a loss tangent (tan ±) of 0.02, and a thickness of 0.8 mm. The parameters of the antenna are optimized using computer simulation. The antenna was designed with an overall PCB footprint of 17mm by 9mm to make the antenna viable as a commercial product. The antennas design parameters were chosen to provide the highest possible gain coefficient and reflection coefficient.

The tuning circuit was designed and simulated to match the T-network characteristics and performance. The antenna and the tuning circuit were then combined into a single circuit and electromagnetic simulations were performed to determine the performance of the system. The results section shows the characteristic reflection coefficient S_{11} characteristics of all three stages of the design process. Computer simulations were used to study the tuning performance of the antenna.

Results:

The antenna was first designed using EM simulation software. A dual band structure was conceived and the reflection coefficient simulated to optimize the design characteristics. The design developed and utilized in the white paper is a multiband antenna design to cover a wide frequency spectrum. The S_{11} parameter is simulated from 1GHz to 10GHz (refer to figure 3).

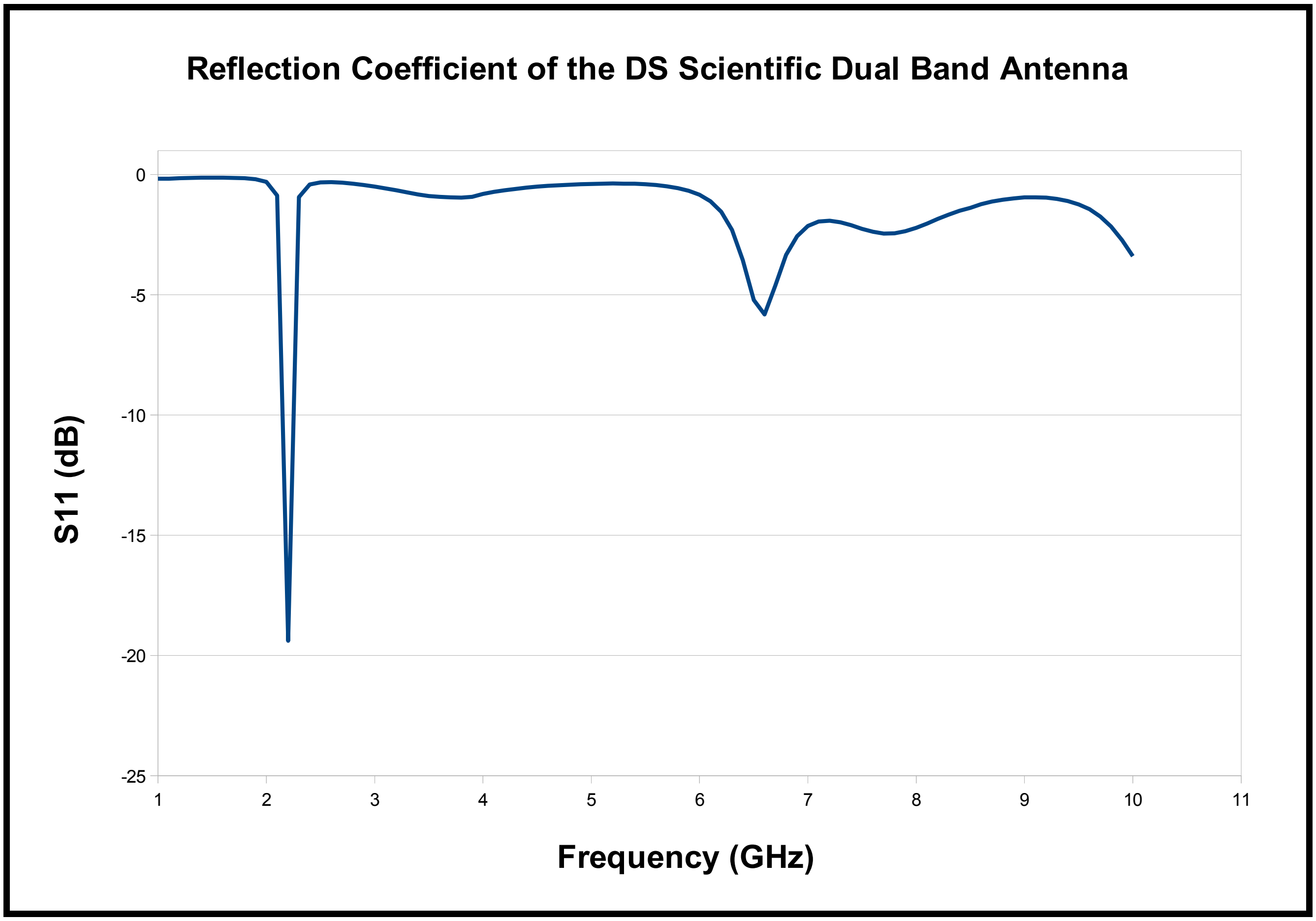

Figure 3: S_{11} Simulation of the Dual Band Antenna.

The antenna design was optimized for a reflection coefficient of approximately -19dB at a frequency of 2.2GHz with a second reflection coefficient dip at 6.6GHz with a reflection coefficient of approximately -6dB. The antenna design was then imported into a spice model and utilized for the tuning circuit design.

The tuning circuit schematic will not be shown due to a pending patent application being filed. During the discussion of the results of the tuning circuit, the circuit will be represented by a block diagram. If any parties are interested in the design of the circuit a none disclosure agreement would be required between DS Scientific and any interested party.

In order to properly characterize the tuning circuit's performance, the tuning circuit is compared to a matching T-network connected in series with the dual band antenna. The schematic representation of the tuning circuit in series with the antenna consists of two capacitors and an inductor connected to GND and the junction of the capacitors connected to the inductor refer to figure 4.

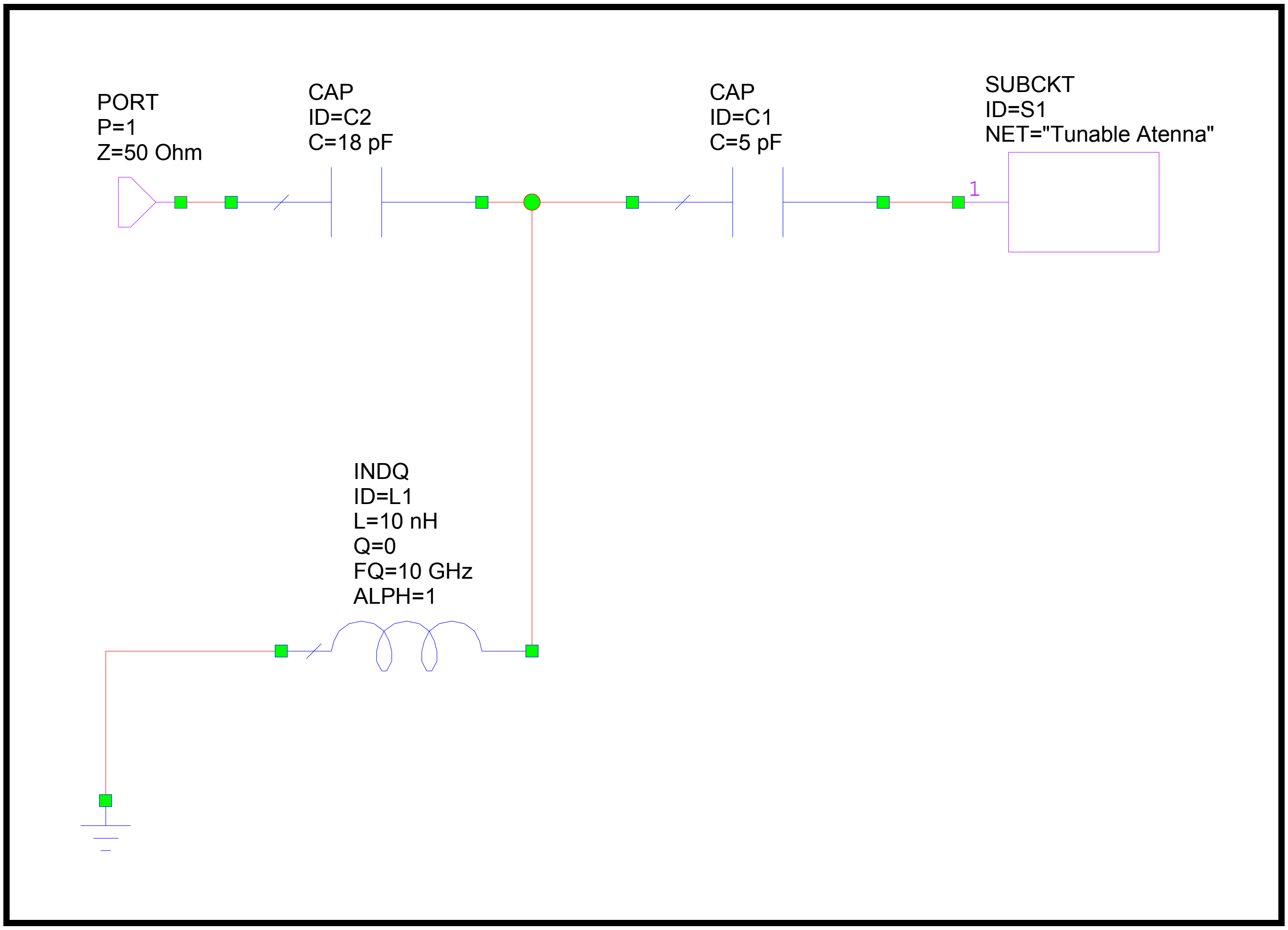

Figure 4: Schematic of T-Network Connected to the Dual Band Antenna.

In tuning, the understanding by the engineers should be varying only one parameter. In the case for this white paper only the C1 capacitor was varied. The results of the different capacitor values are over-laid on the antenna without any matching network. The T-network capacitance C1 was varied between 18pf and 5pf, a simulation was performed to extract the S_{11} parameter (refer to figure 5). The results of the simulation indicates the resonance frequency for the C1 capacitor with a value of 18pF to be -21dB and for a capacitor value of 5pf to be -17dB. By varying the T-network capacitance C1 we can optimize the matching impedance of the antenna closer to the receiver chain. In fact, any variability in the C1, C2, or L1 components will result in similar changes to the return coefficient. The better the match the larger the reflection coefficient.

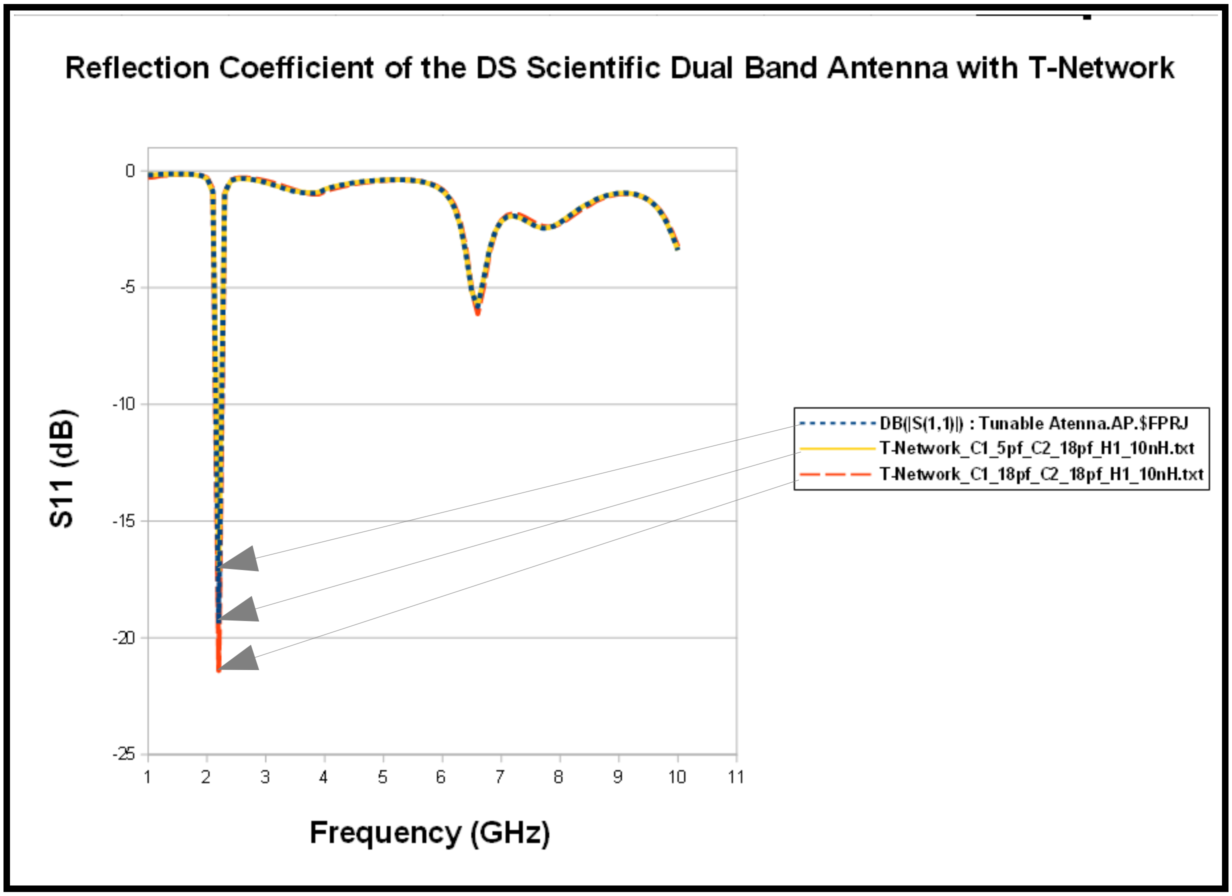

Figure 5: S_{11} Simulation of the Dual Band Antenna with T-network.

Now the S_{11} parameter will be reviewed with the tuning circuit replacing the T-network. The tuning circuit will be referred in the diagram as a block object (refer to figure 6).

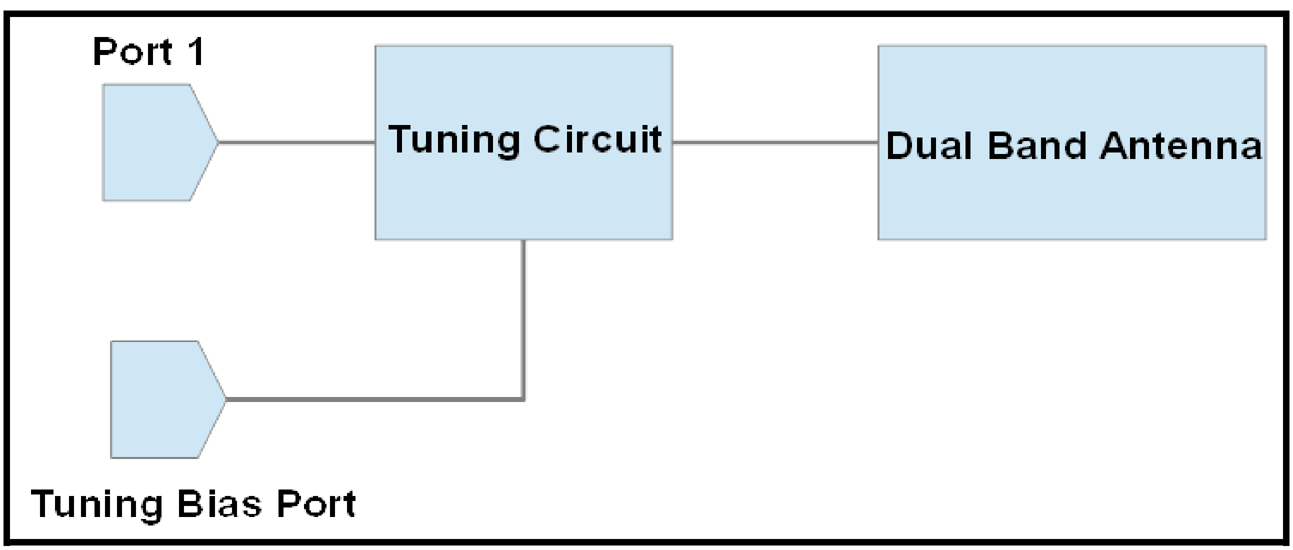

Figure 6: Tuning Circuit with Dual Band Antenna.

The design of the tuning circuit allows the circuit to match the impedance of the receiver chain in this case the port 1 will act as a 50 ohm impedance into the receiver input and the tuning circuit will be adjusted with a single supply voltage, which will result in a larger reflection coefficient similar to the results of the T-network (refer to figure 7).

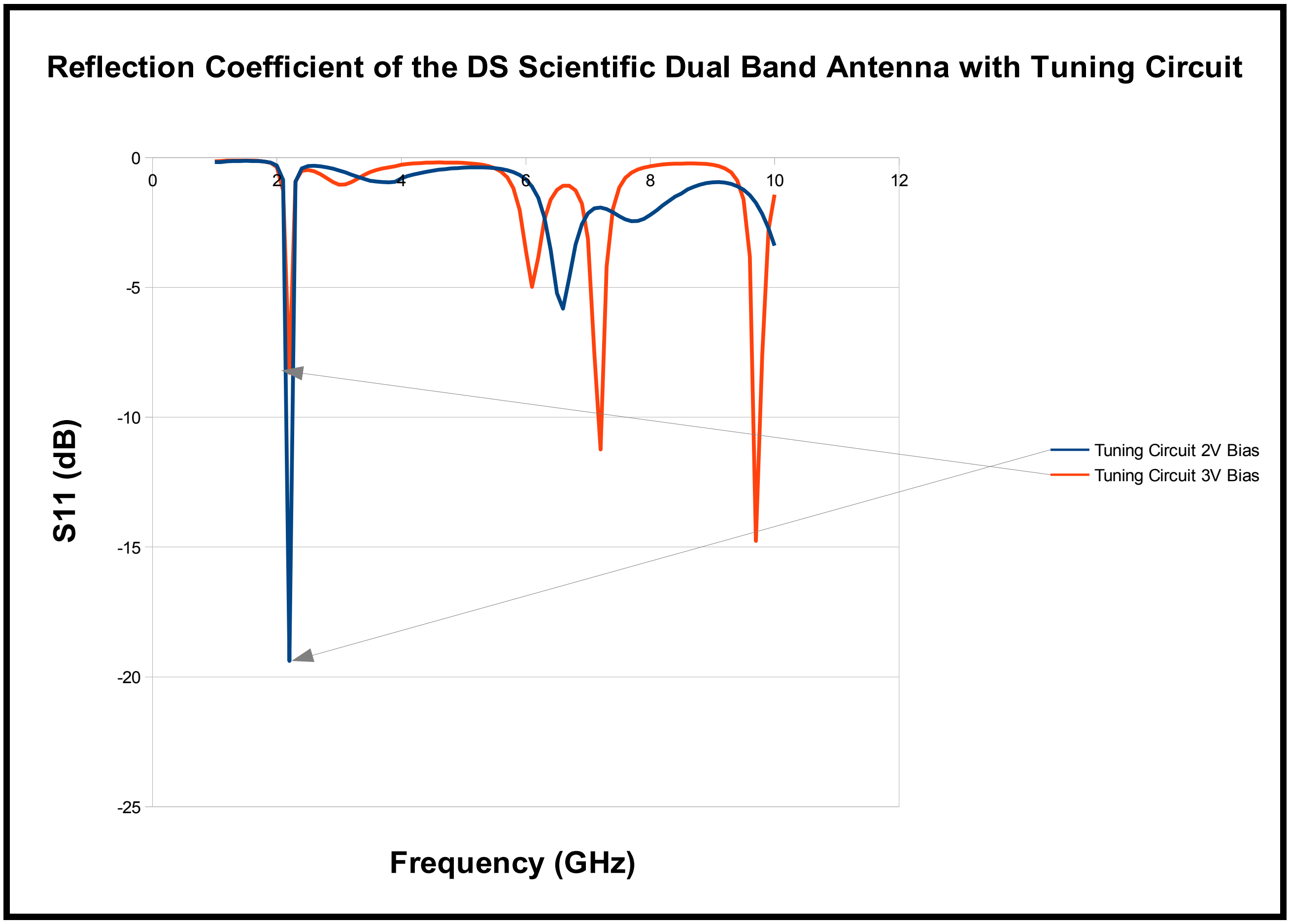

Figure 7: Tuning Circuit with Dual Band Antenna.

In varying the tuning voltage from 3V to 2V the S_{11} match increases from -8dB to -19dB.

Conclusion:

The concept of an antenna tuning circuit or antenna matching circuit is introduced to properly integrate the antenna to the receiver chain. The tuning circuit's functional performance is shown in this white paper. The tuning circuit's matching is demonstrated through simulation of the feasibility of the concept of a single component utilizing a single voltage to match the antenna to the receiver input. Additional features are currently being incorporated in the design. Both the antenna and the tuning circuit are designs that can be licensed with DS Scientific.