Effects of tuning stub on microstrip patch antenna

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Use of tuning stubs to trim the phase of a microstrip feed line or to tune the resonant frequency of a microstrip patch antenna is discussed in this paper. The variation of resonant frequency with stub-length of microstrip patch antenna is also discussed. The experimental results regarding phase shift and resonant frequency with stub-length are in good agreement with the theoretical results.

Key words: Tuning stub, Microstrip patch antenna, Resonant frequency
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1 Introduction

Microstrip elements have proven to be very versatile and have found uses in a variety of applications from satellite arrays to automobile anticollision warning systems. This versatility stems mainly from their structural simplicity, ease of construction, ruggedness, conformability, low profile, and low cost. In addition to these features microstrip elements are capable of producing a variety of different patterns and polarizations.

The foundation upon which the stub line theory is built is the so-called cavity model as modified by Richards et al. This model is best suited for understanding loaded elements, because it can reconstruct the localized field in the vicinity of the loads, yet it is simple enough that basic physical principles useful in design can be developed and is also surprisingly accurate. Ray and Kumar has studied tuneable and dual band circular microstrip antenna with stubs using improved transmission line model. In this paper mainly the effect of tuning stub on the characteristics of microstrip patch antenna, is analysed.

2 Theoretical analysis

Circuit model of the loaded microstrip patch antenna is shown in Fig. 1. The feed reactance can be modelled as

\[ X_f = X_{in} + (f - f_0) X_\Pi \]

Let

\[ f_+ = (1 + 1/2Q) f_0, f_- = (1 - 1/2Q) f_0 \]

The coefficients \( X_{in} \) and \( X_\Pi \) can be approximated as

\[ X_{in} \approx \frac{1}{2} (X(f_+) + X(f_-)) + \frac{R}{4Q} \]

and

\[ X_\Pi = Q f_0 [X(f_+) - X(f_-) + 2R] \]

where \( R = 1/G \). What remains is to determine the input reactance of the ideal cavity at the upper and lower frequencies \( f_+ \) and \( f_- \).

To do this, one simply views the input reactance at the feed port as the input reactance of a loaded two-port network. The \( z \) parameters of the two-port network are the \( z \) parameters of the empty cavity with port 2 located at the feed and port 1 located at the load. The mutual reactance between the ports with respective position vectors \( r_1 \) and \( r_2 \) is just

\[ X_{12} = jG (r_1 | r_2) \]

The input reactance is then

[Image: Circuit model of the loaded microstrip antenna]
\[ X = X_{22} - \frac{X_{12}^2}{X_{11} + X_L} \]

where \( X_{22} \) is the input reactance of the empty cavity at \( r_2 \) and is computed in the same way as \( X_{11} \).

3 Numerical analysis

Use of small tuning stubs to trim the phase of a microstrip feed line, or to tune the resonant frequency of a microstrip patch antenna is discussed here. Because of fabrication tolerances and other effects, the electrical characteristics of a microstrip or stripline circuit may deviate from the design specifications. In a corporate feed network for an array, for example, power dividers, bends, junctions, dimensional tolerances, and substrate inhomogeneities can lead to phase (and amplitude) errors at the array elements, especially for long lengths of feed line. In microstrip antenna fabrication, dimensional tolerances and substrate inhomogeneities can result in significant variation in the resonant frequencies of the elements of a patch array. This can lead to mismatch loss and phase errors due to variable driving point impedances across the array, and is a problem exacerbated by the typically narrow bandwidth of microstrip antennas.

By proper design, the techniques described here can be used to compensate for phase errors over a resonable range, without substantially affecting the loss of a feed line, or the patterns of an antenna element.

A short open-circuited stub in parallel with a microstrip feed line can increase the insertion phase of the line. Figure 2 shows an example of a 50 \( \Omega \) microstrip line on a substrate with \( \varepsilon_r = 2.55 \) and \( d = 0.16 \) cm. The stub is 0.125 cm wide, and the insertion phase and attenuation of the line are plotted versus stub length \( l \), normalized to zero stub length. Observe that phase delay increases as the stub length increases, with negligible attenuation, for \( l \) up to about 0.7 cm, at which point the phase delay is about 20 deg. As \( l \) approaches 1.15 cm, the stub goes through a resonance, with substantial attenuation on the feed line. This loss is due to radiated power. So, to avoid attenuation on the line and undesirable spurious radiation, the stub-length is practically limited to be less than about 0.7 cm. Thus, it is better to use narrow (high impedance) tuning stubs.

Short open-circuited stubs can also be used to load microstrip antennas, in order to adjust the operating frequency. If the stub is small (say less than half the patch length), it will not noticeably affect the radiation pattern, although the stub should be oriented symmetrically with the resonant direction of the patch to avoid cross-polarized spurious radiation.

In Fig. 3 the measured resonant frequency is plotted versus stub-length for stub widths of 1 mm and 3 mm. Greater than 10% tuning range is easily achieved for \( 0 \leq l \leq 1 \) cm, with the wider stub giving a greater variation. This should be more than enough to offset dimensional tolerances, which usually result in errors of no more than a few per cent.

The dimensions of the single stub circular microstrip patch antenna for operation in the L-band were chosen as radius \( r = 3 \) cm; feed point \( x = 0.95 \) cm; and stub width = 0.4 cm. The width of the stub has been kept small, so that the radiation from it is negligible. The substrate parameters are thickness \( h = 0.16 \) cm, \( \varepsilon_r = 2.33 \), and tan \( \delta = 0.001 \). As the stub-length increases from 0.0 to 2.2 cm, the measured resonant frequency decreased from 1.868 to 1.695 GHz (theoretical: 1.866 to 1.700 GHz), and the
measured input impedance decreased from 53 to 30 Ω (theoretical: 52.5 to 28 Ω), thereby reducing the bandwidth for VSWR ≤ 2 from 29 to 9 MHz (theoretical: 28 to 8 MHz). The effect of increase in the stub-length is similar to that of increasing the effective area, which reduces the resonant frequency. With increase in the stub-length, the effective centre of the antenna shifts toward the feedpoint from the physical centre of the circular microstrip antenna and hence the impedance decreases. This yields a tuning range of about 9% with input VSWR less than two. For larger stub-length, the impedance matching can be obtained by shifting the feedpoint towards the edge, which will also improve the bandwidth. The effect of changing the stub-width on tuning the resonant frequency was also studied. As the width of the stub increases, the resonant frequency decreases, with a small reduction in the input impedance. By using an identical patch, it was found that the reflection coefficient of the patch could very easily be turned to less than −45 dB, at any frequency over the range 2.95-3.05 GHz, i.e. a tuning range of 3.33%, without degradation of the match.

4 Conclusions
These types of stub tuners can be applied to many other configurations, including stripline feeds, slotline feeds and circular patches. A varactor may be added at the open end of the stub, to facilitate electronic tuning, instead of the manual tuning described. Bias for this mass be connected to a suitable point on the patch, through a filter. Finally, we might take this opportunity to dispel a myth about the microstrip antenna, which says that its width should be smaller than its (resonant) length, to avoid the excitation of an undesired cross-polarized mode. This is not always necessary, as the patch geometry of Fig. 3 shows that the patch width can be greater than the length (to control input impedance or principal plane beamwidths). The lower frequency resonant mode (resonant in horizontal direction) is not excited because the feed point is located along the midpoint of the long (horizontal) dimension, where this mode has a null in its electric field.

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References