Estimating antenna bandwidth using the bandwidth potential and Q value techniques

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1. Introduction

In many cases the bandwidths of different antennas are compared by simply looking at their S_{11} curves and determining the bandwidth at a desired matching level. However, this approach may be problematic if the antennas are not matched in the same way. Ideally the antennas under comparison should be tuned and optimized so that the antenna impedance is overcoupled and obtains maximal bandwidth around a desired center frequency. Especially when comparing the effect of different parameters on antenna performance the requirement of optimal overcoupling requires a lot of manual work for each parameter combination.

This paper presents two techniques, the Q value technique and the bandwidth potential approach, for estimating the obtainable bandwidth of antennas by using just the antenna impedance data. In both methods implicitly constructed matching circuits are used in the analysis. The methods can easily be applied to non-resonant antennas and can thus be used to select best antenna candidates in term of bandwidth when a parameter sweep is run.

2. Q value technique

The estimation of the antenna Q value from the impedance data was presented in [1]. The Q value estimate at angular frequency $\omega_0 = 2\pi f_0$ is given by

$$Q(\omega_0) = \frac{\omega_0}{2R(\omega_0)} \sqrt{[R'(\omega_0)]^2 + [X'(\omega_0) + |X(\omega_0)|/\omega_0]^2}, \quad (1)$$

where R and X refer to the real and imaginary parts of the impedance and prime denotes differentiation with respect to the frequency. In the derivation of the formula the antenna has been implicitly tuned with a series reactive component to have zero reactance at the center frequency. The Q value can be easily converted to an absolute or relative bandwidth at a desired matching level.

In the derivation of the above formula it has been assumed that the antenna has a single resonance. When a double resonance appears, the formula no longer gives reliable results. Also, small errors in the impedance may lead to large fluctuations of the computed Q value due to the differentiation operator.

3. Bandwidth potential technique

In the bandwidth potential technique a two-component matching circuit obtaining exact impedance match at a given frequency is constructed and the bandwidth through the matching circuit is calculated. The analysis is repeated for all the frequencies of the impedance data. The technique was initially introduced in [2] by the research group at Aalto University (former Helsinki University of Technology).

There are several definitions of bandwidth, and in practice the following definition of symmetric bandwidth has been found to be most practical: the symmetric bandwidth is 2Δ at f_0 if the antenna is matched at a given matching level (e.g. $|S_{11}| < -6$ dB) between $f_0 - \Delta$ and $f_0 + \Delta$.

Instead of matching the antenna impedance exactly to 50 Ohm at the given frequency the bandwidth can be enlarged by slightly overcoupling the impedance match. In the concept of optimized bandwidth potential [3] the two-component matching circuits are optimized for each center frequency so that maximal symmetric bandwidth around the center frequency is obtained.

The bandwidth potential techniques are implemented in the Optenni Lab software [4] where the bandwidth potential calculation takes a few seconds and the calculation of the optimized bandwidth potential takes some tens of seconds.

4. Example

As an example of the application of the bandwidth estimation tools, consider the antenna geometry described in Fig. 1 below. On top of a 100 mm by 40 mm ground plane there are two horizontal strips that are 7 mm above the ground plane. The dimensions are l_1=35 mm, l_2=25 mm, w_1=4 mm, w_2=2 mm and y_2=7 mm. The feeding and shorting pins are 1 mm by 1 mm and there is a 0.5 mm feed gap between the feeding pin and the ground plane. All the parts are modeled as perfect electric conductors with thickness 0.5 mm. The 3D structure was simulated using CST Microwave Studio [5] and the bandwidth potential and Q value estimates were calculated using Optenni Lab.

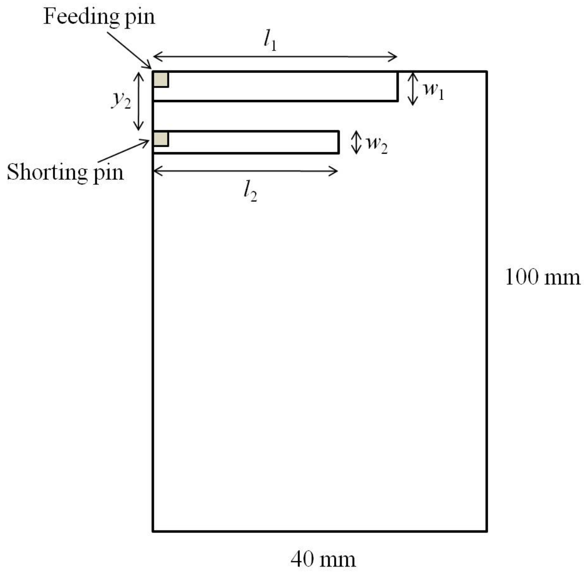

Figure 1: Antenna geometry.

Fig. 2 shows the estimated absolute bandwidth of the antenna using the standard and optimized bandwidth potential and the Q value techniques. The bandwidth is calculated at the 6 dB return loss matching level. At the frequencies where the antenna is narrowband, the differences between the methods are small. Some differences between the bandwidth potential and Q value techniques can be attributed to the different definition of bandwidth as in the bandwidth potential calculation the definition of symmetric bandwidth is used.

At around 2 GHz there is a large difference between the optimized and standard bandwidth potential results. At this frequency, the impedances through the generated 2-component matching circuits are shown on the Smith chart in Fig. 3. The optimized matching circuit is able to fit the double-resonance loop inside the 6 dB return loss circle, thereby enlarging the bandwidth over the standard one.

The bandwidth potential calculations are most useful in combination with parameter sweeps. Fig. 4 shows the S-parameter data and the corresponding optimized bandwidth potential when the height of the antenna is swept from 4 to 7 mm. From the bandwidth potential curve it is clearly seen how the bandwidth is reduced at the lower band while the upper band resonance is shifted upwards when the height is reduced. The maximum upper band bandwidth is obtained slightly below the resonance of the S parameter data. These changes are difficult to see from the S parameter data and even more so in cases where the antenna is not resonating at all.

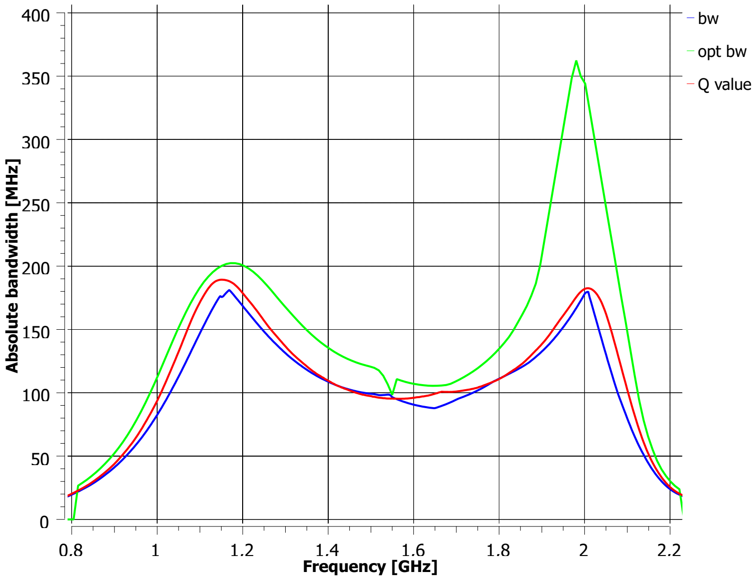

Figure 2: Estimated absolute bandwidth using the standard bandwidth potential (bw), optimized bandwidth potential (opt bw) and Q value techniques.

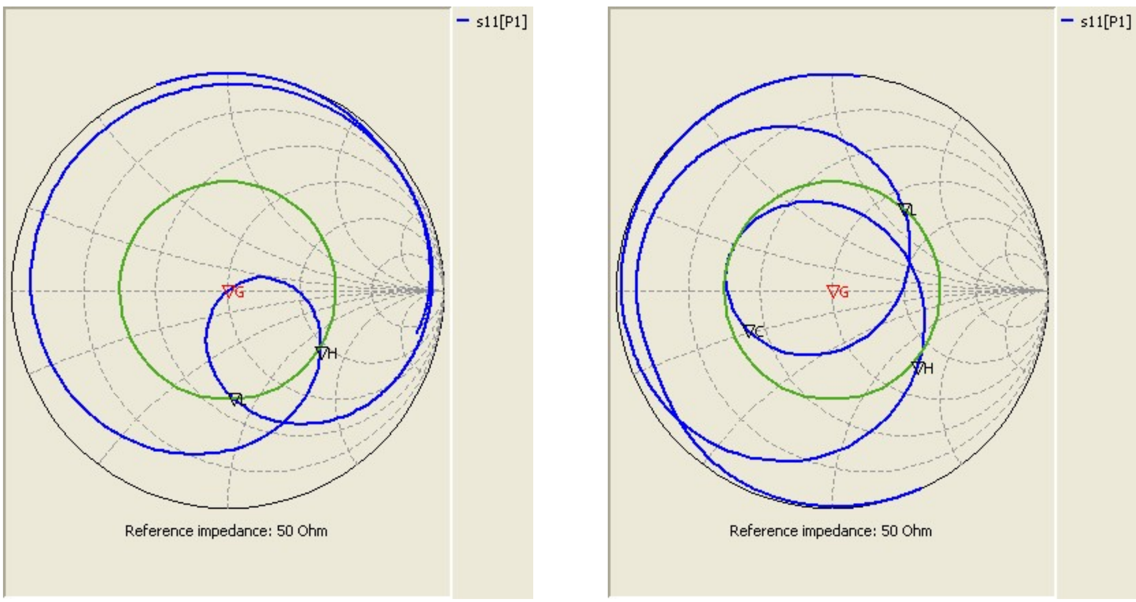

Figure 3: Impedance through a two-component matching circuit at 2 GHz shown on the Smith chart. In the left figure the impedance at 2 GHz is matched to 50 Ohm and on the right the matching circuit is optimized for maximal symmetric bandwidth around 2 GHz. The marker C shows the center frequency (2 GHz), marker G is the generator impedance (50 Ohm) and the markers L and H denote the lower and upper edges of the frequency band for 6 dB matching.

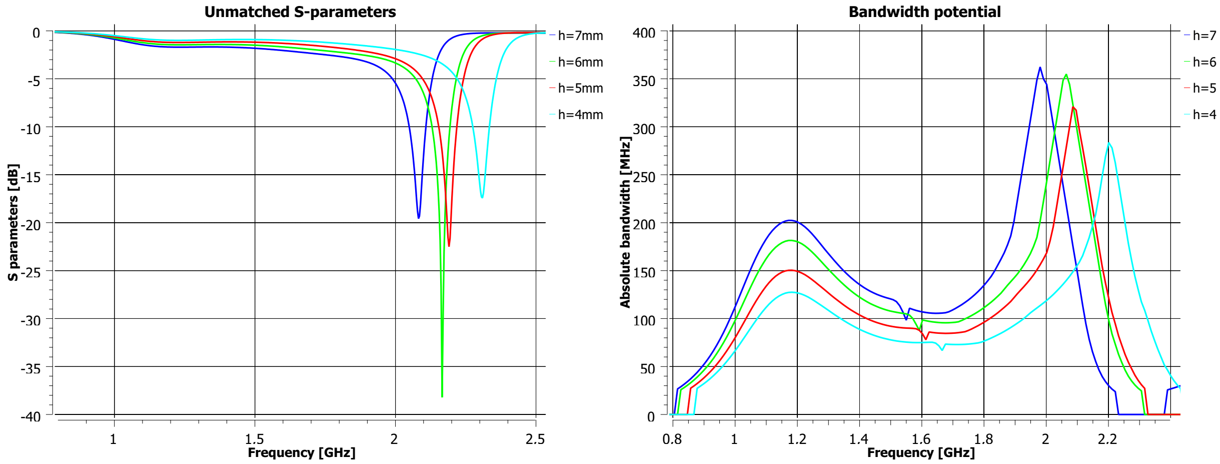

Figure 4: Effect of antenna height to the S parameters (left) and optimized bandwidth potential (right).

5. Conclusions

The bandwidth potential and Q value techniques can be used to estimate the obtainable antenna bandwidth at various frequencies from antenna S parameter data where the antenna need not be resonant. The Q value technique is sensitive to small fluctuations in the impedance data whereas the bandwidth potential calculation is more robust because it constructs the matching circuits and computes the bandwidth through the matching circuit. For antennas with double resonance characteristics the optimized bandwidth potential finds matching circuits with significantly larger impedance bandwidths than the standard bandwidth potential calculation and gives thus much more realistic estimates of the obtainable bandwidth. The calculation of the optimized bandwidth potential can be automated and does not take a long time.

In the bandwidth potential approach the antennas are matched in a similar fashion at all frequencies so that differently matched and non-resonating antennas can be quickly compared without manually tuning the antenna impedance to resonance. The use of the bandwidth potential can speed up the antenna concept creation as the effect of changing antenna dimensions to obtainable bandwidth can be quickly explored. The bandwidth potential approach uses two-component matching circuits and the bandwidth can be further enlarged if more components are used. When the best candidate has been found, its bandwidth can then be optimized by creating an impedance matching structure within the antenna itself or by using impedance matching tools such as Optenni Lab [4].

References

[1] A. Yaghjian and S. Best, "Impedance, bandwidth, and Q of antennas," *IEEE Trans. Antennas Propagat.*, vol. 53, pp. 1298–1324, 2005.

[2] J. Villanen, J. Ollikainen, O. Kivekäs, and P. Vainikainen, "Coupling element based mobile terminal antenna structures," *IEEE Trans. Antennas Propagat.*, vol. 54, pp. 2142–2153, 2006.

[3] J. Rahola, "Bandwidth potential and electromagnetic isolation: Tools for analysing the impedance behaviour of antenna systems," in *Proceedings of the EuCAP 2009 conference, Berlin, March 23-27*, 2009.

[4] Optenni Lab antenna analysis software, www.optenni.com.

[5] CST Microwave Studio EM simulator, www.cst.com.