Wideband Matching Network Design For A V-Shaped Square Monopole Antenna Using Real Frequency Technique

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***Abstract*—In this paper, design and simulation of a wideband matching network for a broadband V-shaped square monopole antenna is presented. Matching network design is unavoidable in most cases even vital to facilitate a maximally flat power transfer gain for an antenna. In the work, the matching network design is done for a particular square monopole antenna with V-shaped coupling element that has essentially bandwidth increasing effect. The V-shaped antenna had been manufactured, tested and analyzed elaborately in a previous work. With this work, it is now equipped by a matching network. 'Real Frequency Technique' (RFT) is employed in matching network design.**

Keywords—impedance matching; microstrip filters; microwave filters; optimization; ultra wideband antennas; ultra wideband communication

I. INTRODUCTION

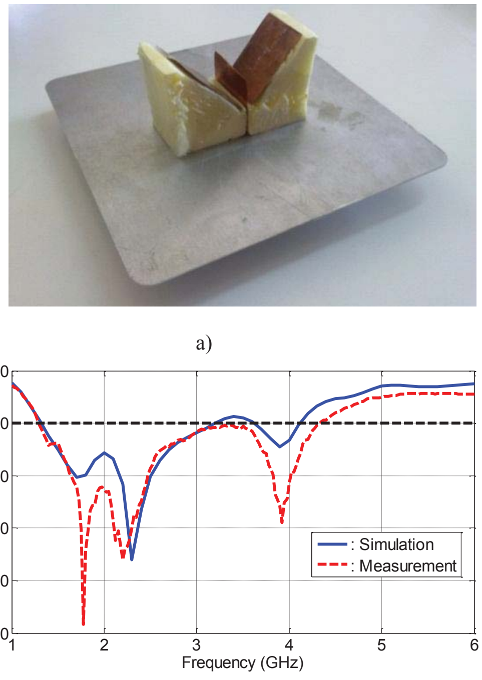
Increasing demand for higher data rates in most recent wireless communication applications require ultra wide band (UWB) antennas. Broadband monopole antennas have appealing features such as wide frequency band, compactness, low-cost, simple structure, light weight, ease of manufacture [1]. Printed circuit board (PCB) in many different shapes such as circular, square, elliptical and triangle are also constructed and proposed for UWB applications to operate over a very wide band in 2.6-14.3 GHz [2]. In a recent work, it is reported that a square monopole antenna with a V-shaped coupling element (V-SPMA), seen in Fig. 1, could become a very satisfactory candidate as an UWB antenna which can cover many communication standards such as cellular phone systems (900 MHz, 1800/1900 MHz) as well as 3G (2.1-2.6 GHz) and Wi-Fi (2.4 and 5.2 GHz) frequency bands [3]. Using such a single V-shaped SPMA in a wireless system could decrease the problems such as system complexities, high costs, high circuitry areas, high DC power consumption caused by many separate narrow-band antennas and its accompanying matching elements. In [3], it is reported that the V-SPMA antenna is manufactured, measured and extensively worked on its performance from the usability point of view as an UWB antenna for the mentioned communication bands above.

Due to difficulties of making antenna, the antenna designer has not always the opportunity to attain a flat power transfer characteristics which is a very desirable feature for maximum power transfer within the usable operating band of the antenna. For the purpose of flattening the in-band power gain characteristics of V-SPMA as much as possible, a matching network design is done. A very well-known, highly successful and commonly used design approach called "Real Frequency Technique" (RFT) is preferred as the design tool, since it has a feature of yielding always convergent solution over an ultra wideband coverage [4-6] when equipped with proper nonlinear optimization algorithms [7,8]. In the work, RFT uses input reflectance data $S_{11}(\omega)$ given for the V-SPMA antenna in [40MHz-26GHz] frequency range to able to obtain an 8-element Butterworth type bandpass matching network (BPMN). BPMN is designed using a Matlab code "*VspmaMatch.m*" inside which RFT runs and the resulting circuit is simulated in MicroWave Office (MWO) of AWR Corporation [9].

II. MATCHING NETWORK DESIGN USING REAL FREQUENCY DIRECT COMPUTATIONAL TECHNIQUE (RFDCT)

Matching network design is preferred to be done using 'Real Frequency Direct Computational Technique (RFDCT)' in which Transducer Power Gain (TPG) of the double matched system seen in Fig. 2 is described in terms of the driving point immitances of the generator $[Z_G \; or \; Y_G]$, equalizer (antenna matching network, BPMN) $[Z_B \; or \; Y_B]$ and the load (V-SPMA antenna) $[Z_L \; or \; Y_L]$. TPG for the V-SPMA antenna matching problem is given as [5]

$$T = \frac{1-|G_{22}|^2}{|1-G_{22}S_{in}|^2} T_{EL} \tag{1}$$



a)

b)

Fig. 1. a) Constructed prototype of the V-SPMA antenna b) Measured and simulated return loss results for the V-SPMA [3].

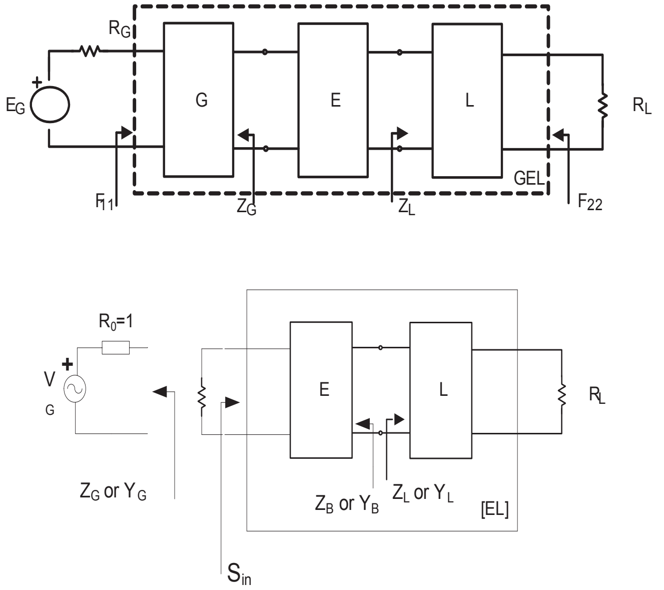


Fig. 2. a) Double matching problem, b) Cascaded connection of two lossless two-ports $[G]$ and $[EL]$.

where the unit normalized generator reflectance and S_{in} is given by

$$G_{22} = (Z_G - 1)/(Z_G + 1) \tag{2}$$

$$S_{in} = \eta_B(j\omega)\left[Z_L(j\omega) - Z_B(-j\omega)\right]/\left[Z_L(j\omega) + Z_B(-j\omega)\right] \tag{3}$$

where $Z_L(j\omega)$ is the input impedance data of the V-SPMA antenna to be computed by using its given input reflectance data $S_{11}(j\omega)$ over the frequency band of interest as

$$Z_L(j\omega) = \left[1 + S_{11}(j\omega)\right]/\left[1 - S_{11}(j\omega)\right] \tag{4}$$

$Z_B(j\omega)$ is the input impedance of the [E] equalizer (BPMN) to be computed by

$$Z_B(p) = \frac{a_1 p^n + a_2 p^{n-1} + \ldots + a_n p + a_{n+1}}{b_1 p^n + b_2 p^{n-1} + \ldots + b_n p + b_{n+1}} = \frac{a(p)}{b(p)} \tag{5}$$

where $p = j\omega$ is Laplace variable. $Z_B(p)$ is a Positive Real (PR) impedance function that is to be determined in the optimization process. The all pass function $\eta_B(p)$ is given as

$$\eta_B(p) = (-1)^{ndc}\, b(-p)/b(p) \tag{6}$$

where ndc is the number of transmission zeros at DC. The transducer power gain T_{EL} of the lossless two port $[EL]$ which is composed of matching network and the antenna is given by [5]

$$T_{EL} = 1 - \left|S_{in}(j\omega)\right|^2 = 4R_B R_L / \left[\left(R_B + R_L\right)^2 + \left(X_B + X_L\right)^2\right] \tag{7}$$

where R_L and $X_L$are real and imaginary parts of the $Z_L(j\omega)$ antenna input impedance, respectively. R_B is the real or resistive part of the $Z_B(p)$ impedance function and it is given by [5]

$$\begin{aligned} R_B(p^2) &= Even\{Z_B(p)\} \\ &= \frac{A_0 p^{2ndc}}{B_1 p^{2n} + B_2 p^{2(n-1)} + \ldots + B_n p^2 + 1} \\ &= A(p^2)/B(p^2) \geq 0, \forall \omega \\ B(p^2) &= \left[c(p)^2 + c(-p)^2\right]/2 \\ c(p) &= c_1 p^n + c_2 p^{n-1} + \ldots + c_n p + 1 \end{aligned} \tag{8}$$

Once the auxiliary polynomial coefficients $\{c_i; i = 1,2,..n\}$ and $A_0 = a_0^2 \geq 0$ of the real part $R_B(\omega)$ are initialized, we can generate the error function ε as follows [5]

$$\varepsilon_i = \frac{1 - \left|G_{22,i}\right|^2}{\left|1 - G_{22,i} S_{in,i}\right|^2} \left\{ \frac{4R_B(p_i) R_{L,i}}{\left|Z_B(p_i) + Z_{L,i}\right|^2} \right\} - T_{bw}(p_i) \tag{9}$$

$$\text{for } \{i = 1,2,\ldots,nd \text{ and } p_i = j\omega_i\}.$$

where nd is the number of frequency data within the optimization band. $T_{bw}(p)$ is a mathematically generated Butterworth type bandpass gain function to be used as the objective or target function curve to be tracked by the optimization algorithm.

The sole purpose of the above formulated process is to determine the $Z_B(p) = a(p)/b(p)$ input impedance as a realizable PR function belonging to the equalizer [E], i.e. the BPMN, by minimizing the error function (9) in a nonlinear optimization process. Then, the corresponding LC lossless network with resistive termination is obtained by applying the very well-known long division process to the $Z_B(p)$ function. Resistive termination is replaced by an ideal transformer with transformer ratio $[R = n^2 : 1]$ which completes the design [5].

Design Steps in Matlab Code "VspmaMatch.m"

- Enter the element number n of the BPMN (bandpass matching network) to be designed.
- Enter normalized frequencies ω_{s1}, ω_{c1}, ω_{c2}, ω_{s2} (lower stopband, lower corner, upper corner, upper stopband frequencies) to be used in constructing the Butterworth template or target gain function of order 2n.
- Set $c = [c_1\ c_2\ ...\ c_n\ 1]$ and a_0 with arbitrary numbers and construct the optimization initial vector by combination of both as $x_0 = [c\ a_0]$.
- Execute an optimization function equipped by a suitable nonlinear optimization algorithm as *x=OptAlgorithm('OptFunc.m', x_0, options); OptAlgorithm* could be chosen as *lsqnonlin* or *fminsearch*. Corresponding line is then typed as
  x=lsqnonlin('OptFunc.m', x_0, options);
  OR *x=fminsearch('OptFunc.m', x_0, options);*
- Execute *Optfunc.m,* to minimize the error function given in (9).
- After obtaining the solution vector $x = [c\ a_0]$ via a successful optimization, construct $A(p^2)$ and $B(p^2)$ even polynomials as in (8) using a_0 scalar and [c] vector.
- Determine $Z_B(p) = a(p)/b(p)$ input impedance of the antenna matching network (equalizer [E]), i.e. BPMN, and synthesize it to obtain the resulting LC lossless network.

III. SIMULATION RESULTS

Designed BPMN matching network together with VSPMA antenna seen in Fig. 3 is simulated in the MWO [9]. Simulated gain curve of this BPMN-VSPMA structure is seen in Fig. 4 in blue color. As understood from this curve, the new structure, i.e. the VSPMA antenna equipped with the BPMN matching network, has the operating band ranging from 800MHz to 5200MHz, a very wide frequency band in which many communication standards could be covered such as GSM, 3G and Wi-Fi. Even though a large frequency band portion between 1.22GHz-5.2GHz has a very small gain deviation of ~0.66dB, a relatively small frequency band between 800MHz-1220MHz has a large gain deviation of ~2.6dB. This case is thought to be caused by the geometry of the antenna that is essentially designed for 2.4GHz RFID applications and could be improved in a future work yielding a gain flatness alongside the whole 800-5200MHz band.

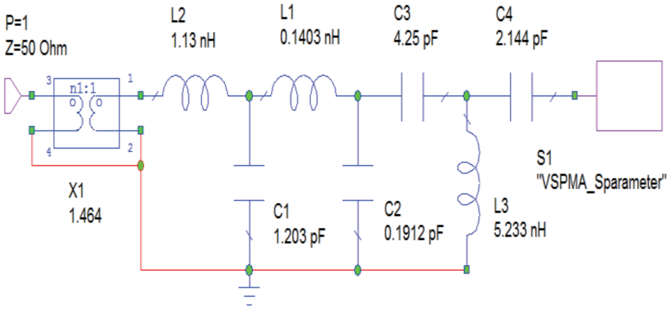


Fig. 3. Designed matching network (BPMN) together with the V-SPMA antenna structure: BPMN-VSPMA.

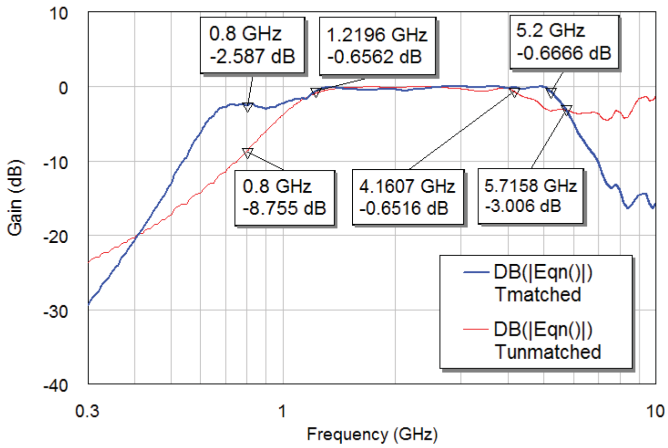


Fig. 4. MWO simulation results: Comparison of matched (blue) and unmatched (red) gain performances.

IV. CONCLUSION

VSMA antenna equipped with the designed matching network (BPMN) achieves a good power transfer gain in a wide (0.8GHz-5.2GHz) frequency range as seen in Fig. 4. Therefore, with the aid of the RFDCT matching network design technique, a single V-SPMA antenna, essentially designed for 2.4GHz RFID applications, has been made a convenient structure that could sufficiently meet applications employing with many communication standards ranging in the 800-5200 MHz frequency band. Full-band (0.8-5.2GHz) gain flatness could be achieved once a new V-SPMA antenna built and equipped by a new BPMN matching network in a future work.

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