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Unit Element Bandpass Filter Design via Simplified Real Frequency Technique for UWB Microstrip Patch Antenna

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Abstract—Design of a UWB (Ultra Wideband) microstrip patch antenna to operate in the first channel of the UWB standard and a bandpass (BP) UE (Unit Element) microstrip filter (BPUEF) for this antenna are studied and presented with promising experimental results. A typical UE BP filter is a lossless 2-port network which is formed with certain number of cascade connected commensurate transmission lines. Based on the simplified real frequency technique (SRFT) in Richards domain, driving point Darlington impedance function of the BPUEF is obtained via optimization such that optimum power transfer would be possible between a PA (power amplifier) and the antenna. Using the UE synthesis, characteristic impedance values of each UE is extracted from the input impedance function. Theoretical design (Matlab), simulation (ADS, Agilent Inc.) and the measurements are shown to be in a high degree of agreement.

Keywords—impedance matching; unit elements; optimization; UWB; simplified real frequency technique; microstrip patch antenna; Richards immittance synthesis.

I. INTRODUCTION

Driving point Darlington immittance (impedance or admittance) function $F(\lambda)$ of a lossless distributed network is expressed as a PRF (positive real function) such that

$$F(\lambda) = \frac{a(\lambda)}{b(\lambda)} = \frac{a_1\lambda^m + a_2\lambda^{(m-1)} + \dots + a_m\lambda + a_{m+1}}{b_1\lambda^n + b_2\lambda^{(n-1)} + \dots + b_n\lambda + b_{n+1}}, \quad (1)$$

where $|m-n| \leq 1$

where Richards variable $\lambda = j\Omega = j \tan(\omega\tau)$ is a trigonometric mapping of physical frequency ω [1]. A typical matching network, such as seen in Fig. 1.b, can be obtained by proper synthesis of its driving point Darlington impedance function $F(\lambda) = Z_F(\lambda) = a(\lambda)/b(\lambda)$ utilizing our Matlab based “high precision Richards immittance synthesis package” [2]. $Z_F(\lambda) = Z_m(\lambda)$ is the front-end or driving point input impedance function subject to the “Unit Element (UE) Synthesis” [1] which yields a distributed element network composed of cascade connected certain number of commensurate (i.e. physically equal length) transmission

lines. Resulting synthesized UE network could consists of transmission lines such as Z_i ($i=1,2,\dots,k$), open-stubs (C_2) and short-stubs (L_3), all are commensurate lines. Commensurate lines are also known as unit-elements (UEs) [1].

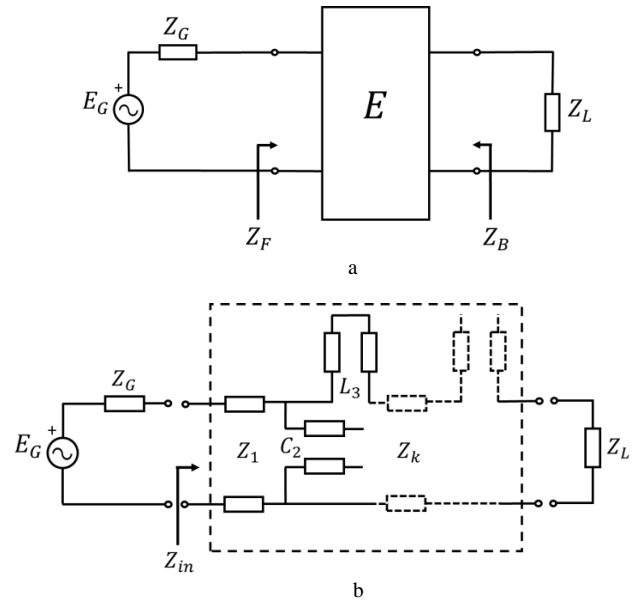


Fig. 1. a) Double matching problem, b) Construction of a 2-port lossless distributed network with commensurate lines (or UEs) [1].

In this work, first, a UWB microstrip patch antenna is designed to operate in the first channel (3.24-3.74GHz) of UWB standard (3.1-10.6 GHz) for low-power indoor data transfer applications; then secondly a BP UE filter (BPUEF) is designed to drive this antenna in the said frequency band. Both the antenna and the BPUEF is designed, simulated, prototyped on an FR4 PCB material. It has been observed that the theoretical, simulation and measurement performances are all in a good agreement with each other.

II. FILTER DESIGN IN RICHARDS DOMAIN VIA SRFT

The double matching problem seen in Fig. 1.a can be thought as a single matching problem assuming that Z_G is a complex impedance and $Z_L=R_L$ is a resistive termination. Furthermore, assuming $Z_G=R_G$ with $Z_L=R_L$, i.e. both the generator and the load sides have resistive terminations, the problem is known as a filter problem. Transducer power gain (TPG), or shortly gain, of this filter, is expressed in terms of reflectance function such that [1]

$$T(\omega) = 1 - |\Gamma_F(\lambda)|^2, \quad \lambda = j\Omega = j \tan(\omega\tau) \quad (2)$$

where $\Gamma_F(\lambda)$ is the front-end reflectance function of the equalizer network [E] (i.e. BPUEF) that is to be designed and it is expressed as a rational function as

$$\Gamma_F(\lambda) = \frac{h(\lambda)}{g(\lambda)} = \frac{h_1\lambda^n + h_2\lambda^{(n-1)} + \dots + h_n\lambda + h_{n+1}}{g_1\lambda^n + g_2\lambda^{(n-1)} + \dots + g_n\lambda + g_{n+1}} \quad (3)$$

where $h(\lambda)$ is the numerator polynomial having real arbitrary coefficients, and $g(\lambda)$ is the denominator polynomial that must be *strictly Hurwitz*, i.e. all its roots must reside in the open LHP (left half plane) of Richards plane $\lambda = \Sigma + j\Omega$, and thus it excludes the roots on the $j\Omega$ axis. Main aim in the design of BPUEF is to compute h polynomial coefficients by a nonlinear optimization which then enables to compute coefficients of polynomial g in such a way that the resulting filter would be formed with only k number of cascade connected UEs whose characteristic impedances are designated by Z_i ($i=1,2,\dots,k$).

In the course of SRFT (Simplified Real Frequency Technique) [3] based design of a filter, a predetermined target gain function $T_i(\omega)$ is tracked by a gain function having mathematical form of (1), which is evaluated at all frequencies in the optimization range such that

$$d_i = T(\omega_i) - T_i(\omega_i), \quad \omega_b \leq \omega_i \leq \omega_e, \quad i=1,2,\dots,nd \quad (4)$$

$$\text{minimize} \left\{ \sum_{i=1}^{nd} |d_i|^2 \right\} \text{ to yield } h, g \text{ of } \Gamma_F = h/g \quad (5)$$

where d_i is the error evaluated at the i th frequency ω_i among nd number of equi-spaced frequencies in the optimization range $[\omega_b, \dots, \omega_e]$. In the course of the execution of the optimization, SSE (sum of squared errors) [4] approach eventually yields optimized h and g polynomials which gives us the impedance function of the network (i.e. filter) such that,

$$Z_F(\lambda) = a(\lambda)/b(\lambda) = (g(\lambda) + h(\lambda))/((g(\lambda) - h(\lambda))) \quad (6)$$

Running the UE synthesis function in the main code with $z_{ue} = UE_sentez(h,g)$ [1], all UE normalized characteristic impedance values z_i ($i=1,2,\dots,n, n+1$) are extracted as $z_{ue} = [z_1 \ z_2 \ \dots \ z_n \ z_{n+1} = r_{n+1}]$ where the $(n+1)$ th element, i.e. r_{n+1} , is actually the resistive termination of the resulting UE element filter.

III. A UWB MICROSTRIP PATCH ANTENNA DESIGN

Monopole microstrip antenna usage has been more and more common in today's wideband data transfer applications. In this work, a rectangular microstrip patch antenna [5, 6] to operate within 2.4-4.2 GHz frequency range is designed. Parameters of the designed antenna is given in Fig. 2.

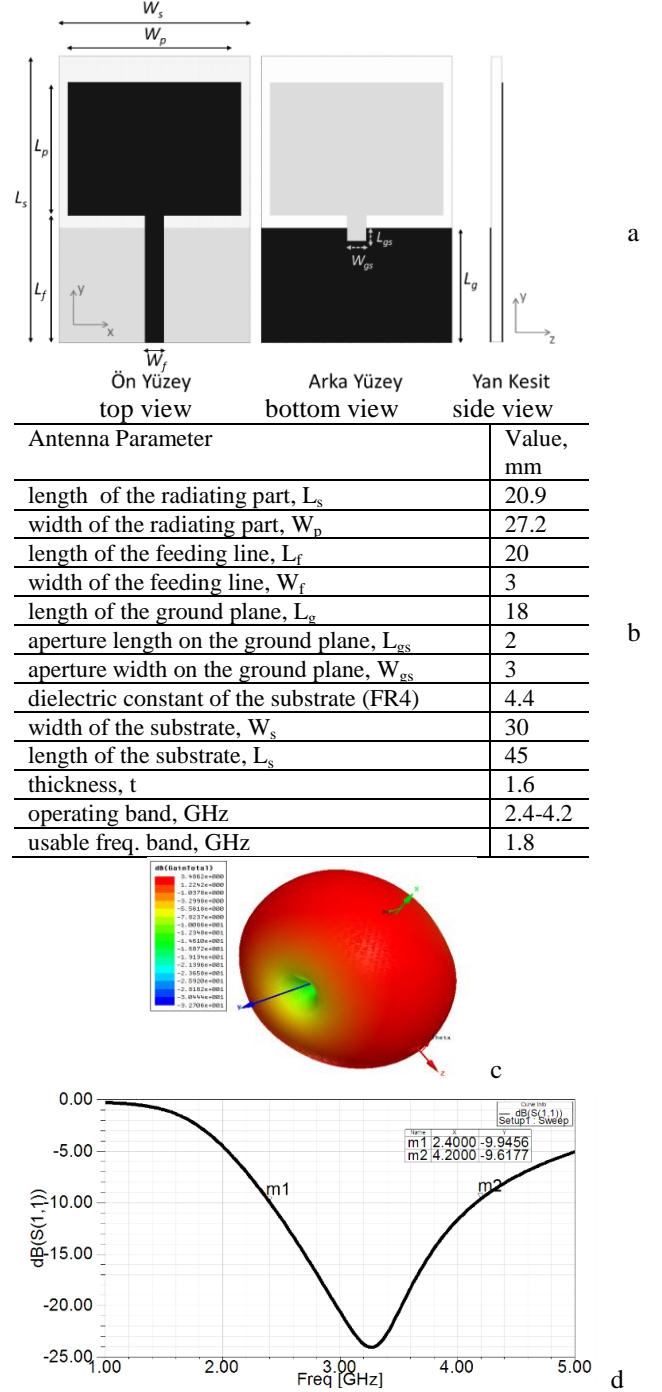
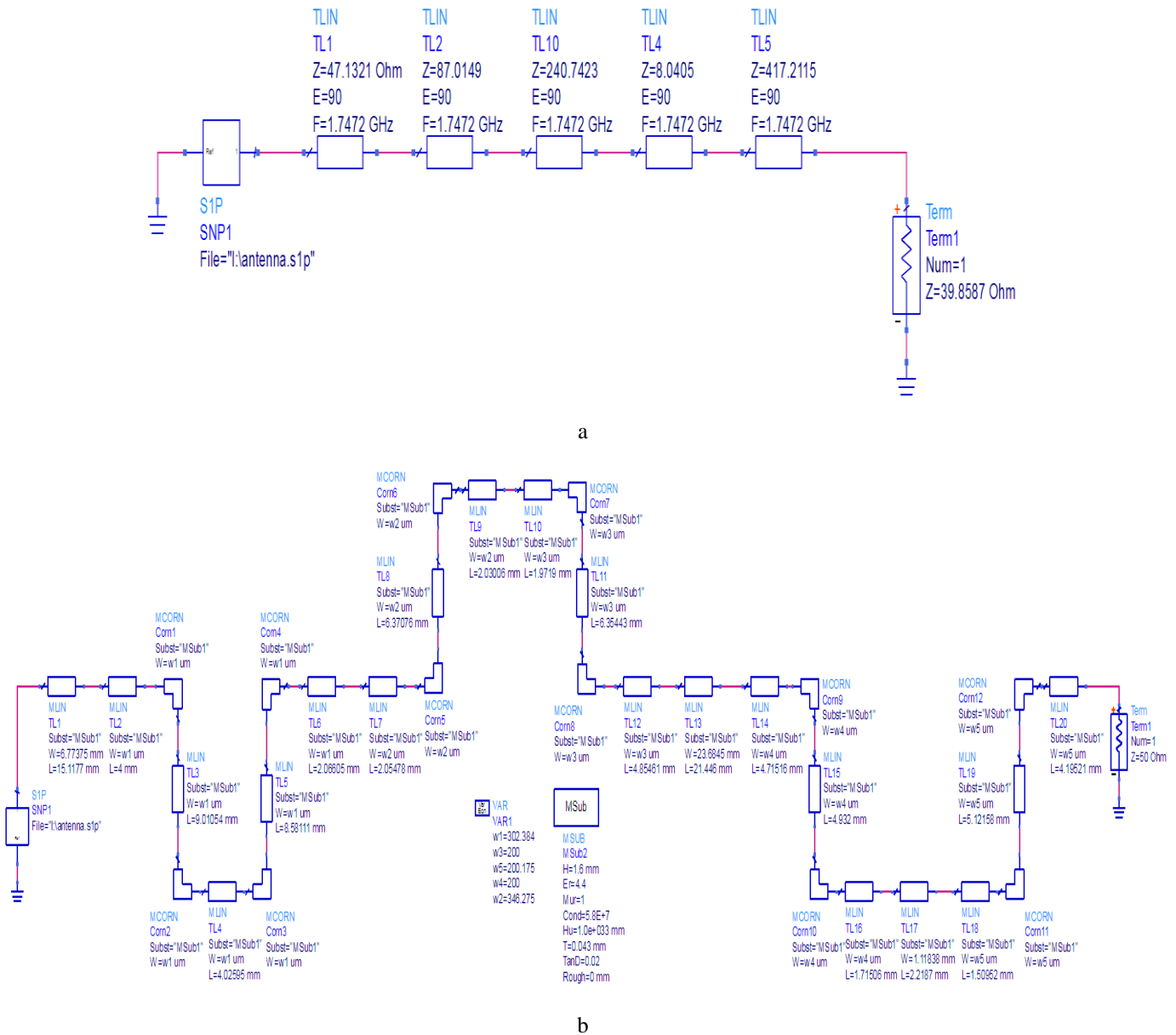


Fig. 2. a) Geometry of the rectangular monopole microstrip, b) antenna parameters, c) 3D radiation pattern; green: x-axis, blue: y-axis, red: z-axis, d) antenna reflection.

IV. DESIGN, PROTOTYPE AND MEASUREMENTS OF BP UE FILTER

The system that comprised of the antenna and the BPUEF to be designed is desired to operate within 3.24-3.74GHz UWB band for short range, low power and high rate wireless data transfer. In the developed Matlab code *UEbpfiler_design.m*, it is sufficient to enter only $F1=3.2448$ (GHz), $F2=3.7440$ (GHz), $ILR=0.2$ (dB) and $IL=60$ (dB) parameters. The code yields h and g polynomials and the characteristic impedance values of the UEs as $Z_{ue}=[47.13 \ 87.01 \ 240.74 \ 8.04 \ 417.21 \ 39.86]$ Ohm as seen in the ADS circuit schematic in Fig. 3.a (see also Table 1). The gain performance of the designed BPUEF by the Matlab code

UEbpfiler_design.m is shown in Fig. 4. Note that the UEs with the values 240, 8 and 417 are impractically too low or high, therefore the circuit needs to be reoptimized to make these values practically realizable, say between 15 and 120 Ohm by keeping the termination resistance of 39.86 Ohm fixed at 50 Ohm. In the course of reoptimization, 240 and 417 Ohm impedances were divided in several transmission lines with smaller value impedances, whereas 8 Ohm is directly set to 15 Ohm. Fig. 3.b shows the final reoptimized circuit schematic with practical UE impedance values. Layout (ADS), manufactured prototype pcb board are shown in Fig. 5.a and b. Simulated and measured gain performances are shown in Fig. 5.c.



Şekil 3. a) Matlab design result: BPUEF circuit schematic (drawn in ADS), b) reoptimized circuit schematic.

Table 1. Outputs of the Matlab design code *UEbpfilter_design.m*

h	52.1064	-188.5542	128.9070	-11.0798	3.9977	-0.1136
g	52.1064	202.3931	180.8228	51.8353	10.9454	1.0064
z_ue (normalized imp.)	0.9426	1.7403	4.8148	0.1608	8.3442	0.7972 Ohm
Z_ue (actual imp.)	47.1321	87.0149	240.7423	8.0405	417.2115	39.8587 Ohm

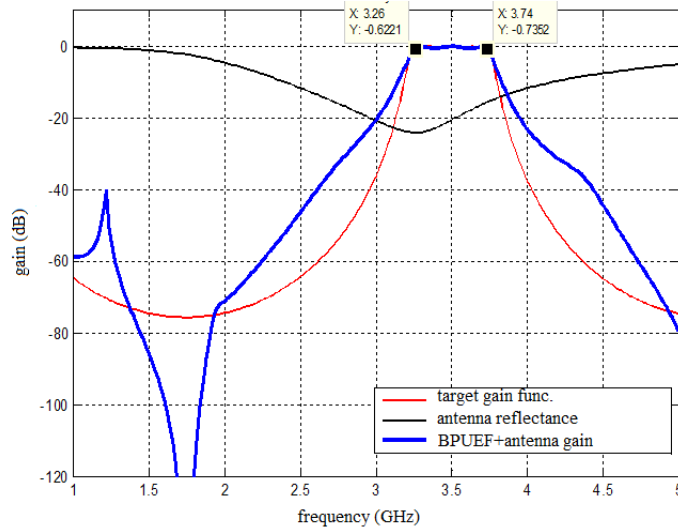


Fig. 4. Design result from the Matlab design code: Gain performance of the designed BPUEF.

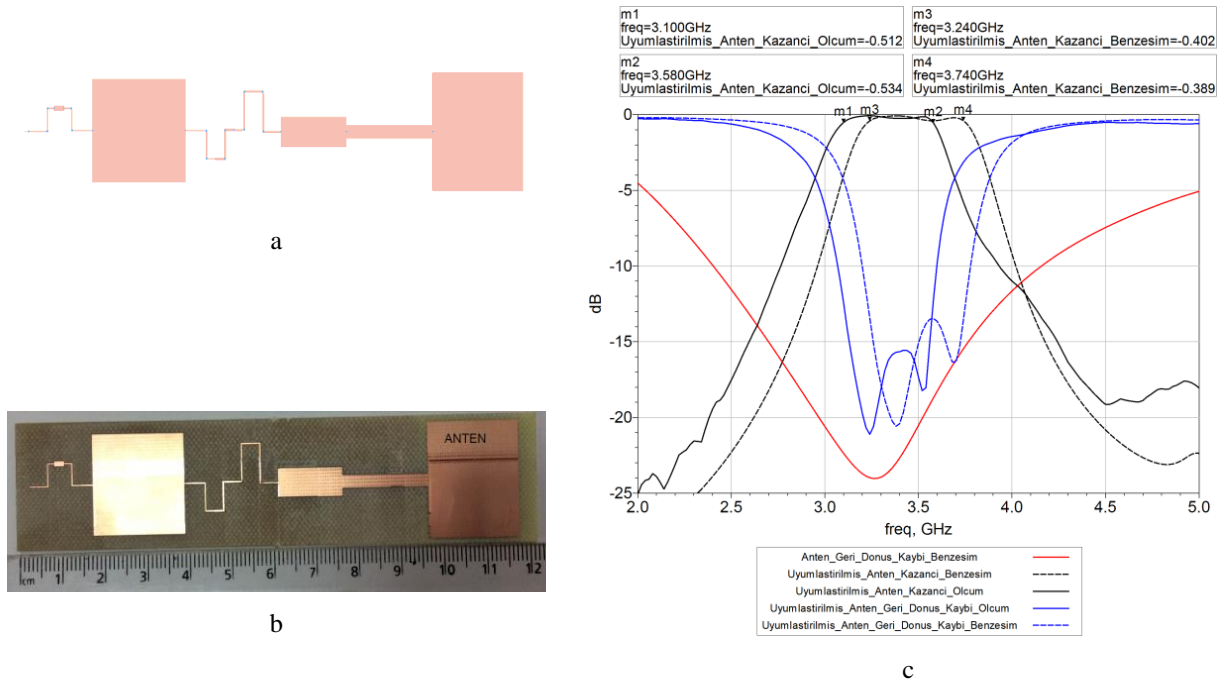


Fig. 5. a) Layout (ADS), b) manufactured prototype pcb board (~12cmx3cm), c) ADS simulation vs. prototype measurements: solid/dashed black-gain (measurement/sim.), solid/dashed blue- S_{11} (measurement/sim.), solid red-antenna S_{11} (measurement/sim.).

V. CONCLUSIONS

In the work, a UWB microstrip patch antenna and a BP UE filter (BPUEF) is designed using the developed Matlab code based on SRFT. The system that is comprised of antenna and BPUEF is designed, simulated and prototyped on an FR4 PCB material. It has been observed that the theoretical, simulation and measurement performances are all in a good agreement with each other. Though the prototype board has been manufactured in the university's lab environment, the work can be repeated in the future using high performance microwave grade laminates such RT5870/80 of Rogers Inc., or other laminates from Taconic Inc. and manufacturing can be made by high-tech companies [7] having capabilities to process those laminates to improve performance of the board. One important issue is that the UEs with high characteristic impedance values synthesized by the Matlab code would be lowered if the reoptimization is done via a Matlab function to be developed in the future.

VI. ACKNOWLEDGMENTS

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