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ТЕХНОЛОГИИ РАДИОСВЯЗИ, РАДИОВЕЩАНИЯ И ТЕЛЕВИДЕНИЯ

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UWB PULSE SHAPE FILTER AND ANTENNA DESIGN FOR ETSI MASK

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A new pulse shape filter and a planar monopole antenna for satisfying the ETSI mask requirements on UWB communication systems radiation levels are designed in the paper. The microstrip filter on the basis of Chebyshev type of the 11th order is designed in the way that can transform any UWB noise-like signal to the one, fitting the 6 ÷ 8,5 GHz band of the ETSI mask. The total filter size is 27×16 mm^2. The UWB planar antenna configuration was constructed on the basis of fractal technology, that allowed to provide impedance matching in the band 3,09÷15 GHz, while remaining the small dimensions (34×41 mm^2), which are inherent to UWB band. Both devices are made from the same material and can be easily implemented on one printed circuit board, that will reduce loss and increase the efficiency of ETSI mask matching and electromagnetic compatibility with the existing wireless devices.

Ключевые слова: communication; ETSI mask; pulse shaping; filtration; fractal antenna

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Introduction

Modern Ultra Wideband (UWB) communication systems still provide a lot of interest to the developers and manufacturers of telecommunication equipment due to its unlicensed usage, high data rates, not comparable with any wireless technology, high noise immunity and stability for multipath propagation, low power consumption and small size. The possible UWB application area is still being extended by industrial, commercial and consumer fields, such as connection between portable devices (video cameras, high definition (HD) plasma displays, DVD players, multifunction and I/O information devices [1]).

According to the last decision of the European Telecommunications Standards Institute (ETSI) № ETSI EN 302 065-1, V1.3.1 (2014-04), [2], the final restrictions for UWB signals were set (Fig. 1), with the most appropriate operational band 6÷8,5 GHz. Its choice is justified by the fact that the equivalent isotropically radiated power (EIRP) level in the other bands is too low, not providing any opportunity for correct reception and detection.

Most of the previous work on pulse shape filter design was aimed at FCC mask, which is much more different than ETSI mask. In [3] a new band pass filter (BPF) was designed as a cascade of two resonators: electromagnetic band gap and multimode fork. It cuts the frequencies outside the band 3,1 … 10,8 GHz. Parallel coupled microstrip line with L- and C-shaped resonators was applied in [4], that also provided the band 3,1 … 10,8 GHz. Two filters on the basis of quarter-wave length short-circuited stubs models were proposed by the authors in [5] and [6]. The first example was designed by extracting parasitic elements and discontinuity, while the second version consisted of two pairs of joint stubs that reduced the filter size.

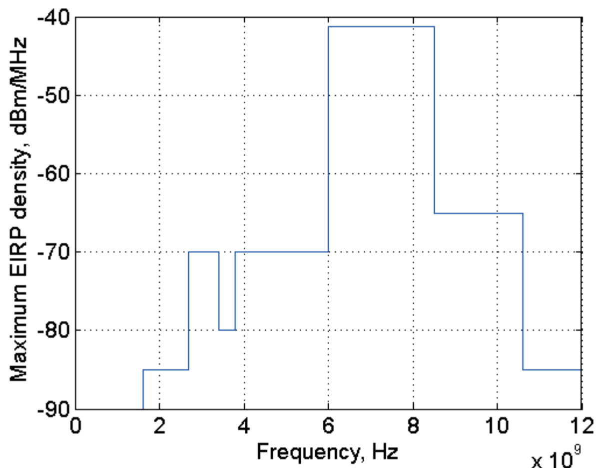


Fig. 1. ETSI mask for UWB communication systems

Nevertheless it should be mentioned that the emission limits, set by FCC mask, still can cause the undesirable interference with the existing wireless systems, so ETSI mask should provide more opportunities for protecting wireless communication systems [7]. In this case the certain work must be done for fulfilling the ETSI requirements and ensuring electromagnetic compatibility within the European Union.

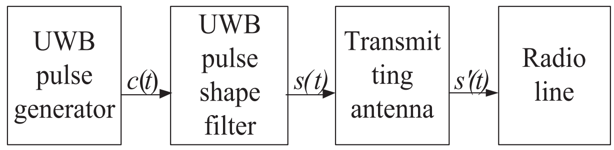


Fig. 2. UWB communication system (transmitting part)

Regarding fractal antennas there are a lot of interesting configurations, proposed recently. Plane fractal «Pythagoras tree» was applied for forming the radiating part in [8]. The antenna operates in the band 6 … 8 GHz, the antenna's size – 29×24 mm^2. Fractal antenna on the basis of «Sierpinski triangle», which shape was optimized with PSO algorithm, was presented in [9] for DVBH, GSM and UMTS bands, dimensions – 66×74 mm^2. The other resonant fractal antenna was developed in [10], where four elements in the shape of 2^{nd} iteration Koch curve were cut from the rectangular radiating plane. The antenna radiates in the WLAN band IEEE 802.11b (2,4 GHz) and IEEE 802.11a (5,8 GHz). Antenna's size – 60×60 mm^2. So it can be concluded that since fractal technology can provide reducing the antenna's size, so fractal UWB antenna design is still interesting and required.

In this paper the design of UWB pulse shape filter and antenna as parts of the communication system, presented at Fig. 2, will be considered. In Section II the UWB pulse shape filter for ETSI mask restrictions will be developed and simulated, also its features will be discussed. Section III will be devoted to the fractal highly efficient UWB antenna design, which characterized with small size and simple structure. The conclusion will be done in Section IV.

Pulse Shape Filter Design

A novel compact UWB pulse shape filter with operation band fitting 6 … 8,5 GHz band of the ETSI mask is proposed. It is designed as BPF on the basis of CMOS technology, compatible with integrated circuits, which is a great advantage for fabrication. The preliminary filter draft is shown at Fig. 3. It's composed of dielectric substrate with the main filter part on its top and the ground - on the bottom side. The filter is supplied with two coplanar waveguide ports via SMA connectors and was set to be matched with 50 Ohm resistance.

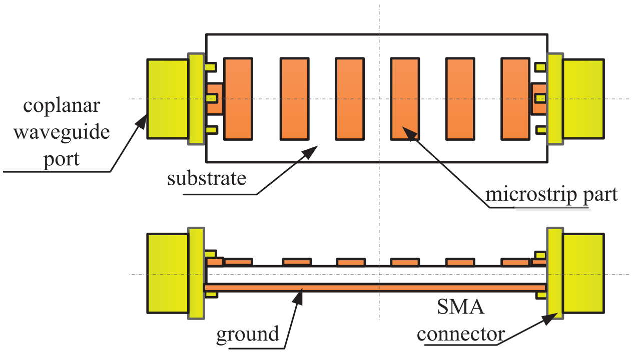


Fig. 3. Microstrip BPF outline

The simulation has been done with software package Agilent GenesysTM. It involved facing with the following problems and their solutions:

- the manufacturing complexity of small-sized filter units, which order is hundreds µm, was fixed by setting the critical dimensions of the BPF during the optimization;
- the impact of parasitic connection circuits and heat rejection was reduced by applying the noise suppression methods;
- requirements of high manufacturing accuracy and material homogeneity were considered while selecting the substrate type and the BPF structure.

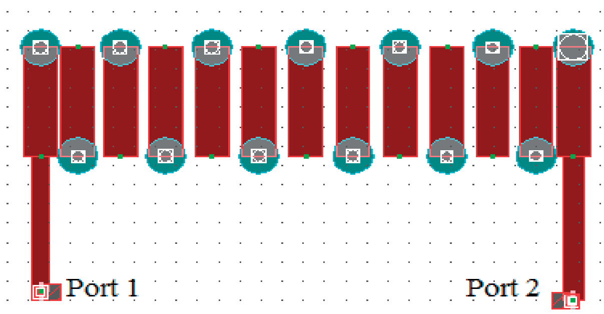


Fig. 4. BPF layout

The proposed BPF is based on Chebyshev type of the 11th order and made on Rogers RO4350 1oz 30 ED 30 mil laminate (ε_r = 3,48±0,05; tg δ = 0,004). It is matched to 50 Ohm impedance and has interdigital structure. The basic selection criteria of filter characteristic was the gain slope.

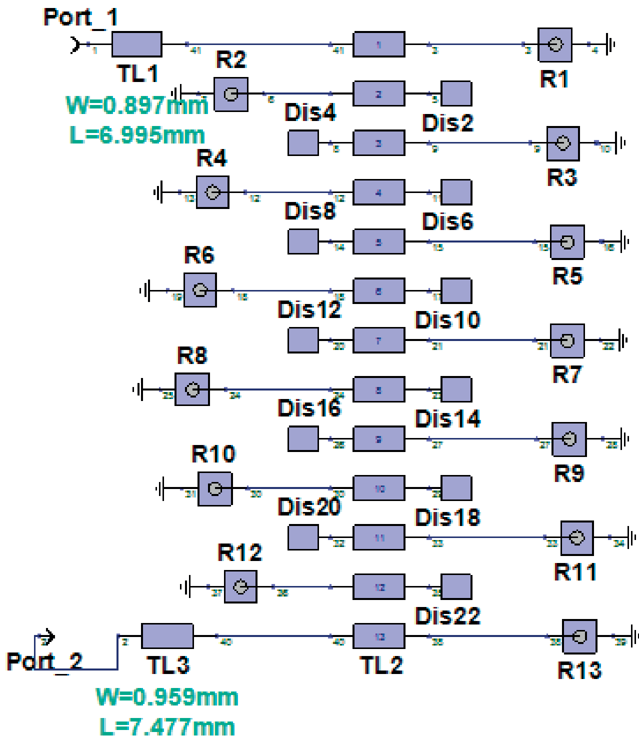


Fig. 5. BPF equivalent circuit model

The main filter characteristics, which were optimized, are the return loss S_{11}, the insertion loss S_{21} and VSWR (Voltage Standing Wave Ratio), [12]. The first one represents the amount of power, reflected from the input. The second – the power, transferred from the input to the output. And VSWR, according to the name, is the ratio between standing wave maximum and minimum amplitudes. So let us define the cost functions as:

- the return loss S_{11}:

$$S_{11} < -30 \text{ dB if } \Delta f = 6 \div 8{,}5 \text{ GHz}; \quad (1)$$

- the insertion loss S21:

$$S_{21\ \mathrm{BPF}} < -44 \text{ dB if } \Delta f = 0 \div 6 \text{ and } 8{,}5 \div 14 \text{ GHz}; \quad (2)$$

- VSWR:

$$\mathrm{VSWR} < 1{,}3 \text{ if } \Delta f = 6 \div 8{,}5 \text{ GHz}. \quad (3)$$

The optimization was performed in the ordinary least squares technique.

Fig. 4 shows the layout of the designed BPF. The basic section of the filter has train structure. The red strips are copper conductors, and the blue circles are the groundings. The designed filter's dimensions are 27 mm × 16 mm.

Table 1. Filter's optimized parameters

Name	Description	Changes range, mm	Final value, mm
W_1; W_3	Lead's strips width	W=[0,2;0,201;…3]	0,897; 0,959
L_1; L_3	Lead's strips length	L=[0,2;0,201;…9]	6,995; 7,477
W_2	1..13 strips width	W_2 =[0,2; 0, 201; …4]	1,561
L_2	1..13 strips length	L_2=[0,2; 0,201;…12]	5,629
$S_{1..12}$	Gaps between 1..13 strips	$S_{1..12}$=[0,2; 0,201;…1]	0,2; 0,456; 0,582; 0,629; 0,649; 0,662; 0,666; 0,665; 0,651; 0,615; 0,481; 0,2.
$R_{1..13}$	Radius of microstrip viahole	$R_{1..13}$ =[0,2; 0,201;…1]	0,326; 0,305; 0,314; 0,321; 0,319; 0,314; 0,311; 0,309; 0,306; 0,302; 0,288; 0,296; 0,675.

Since every conductor and element of the filter layout represents the certain object of the electrical circuit, so an equivalent filter circuit model, shown at Fig. 5, can be developed. It can be used to explain the working principle of the proposed BPF, and its units parameters after optimization are presented in Table 1. The abbreviations, used at Fig. 5, are: TL – transmission line leader microstrip; R – resistance; Dis – microstrip viahole (unused port). S_{11} and S_{21} characteristics of the proposed BPF are presented at Fig. 6. It can be seen that its band pass performance is good enough, since cut-off frequencies have sharp rejection, and occupy the bands only 300 MHz, from 5,7 to 6 GHz for low boundary and at 8,5 to 8,83 GHz for high border. So actually it passes the frequencies in the band 6,5 … 8 GHz. S_{11} level is also below -30 dB in the desired operation band.

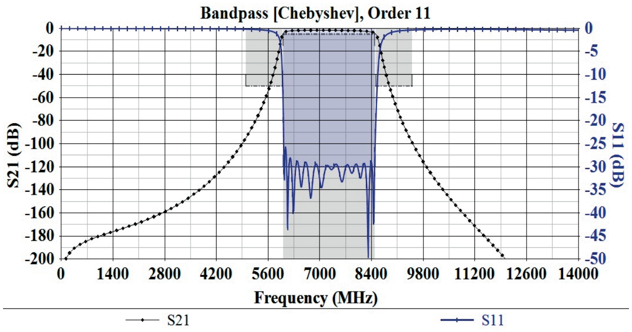


Fig. 6. BP Filter's S_{11} and S_{21}

BPF's VSWR is shown at Fig. 7. Obviously the initial requirement for VSWR < 1,3 in the band Δf = 6 … 8,5 GHz is perfectly completed. Furthermore VSWR value in this band is less than 1,1.

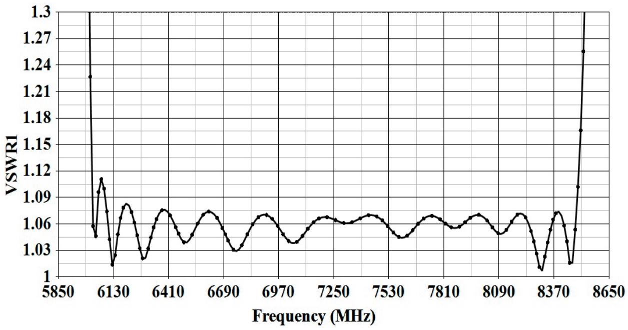


Fig. 7. BP Filter's VSWR

Also group time delay (GTD) is considered as one of the most important filters features: it must be constant in the operation band with the maximum acceptable deviation of 0,8 ns. GTD is presented at Fig. 8: it can be seen that after the peak of 4 ns at 5,9 GHz the average value is about 2 ns in the band 6 … 8,5 GHz.

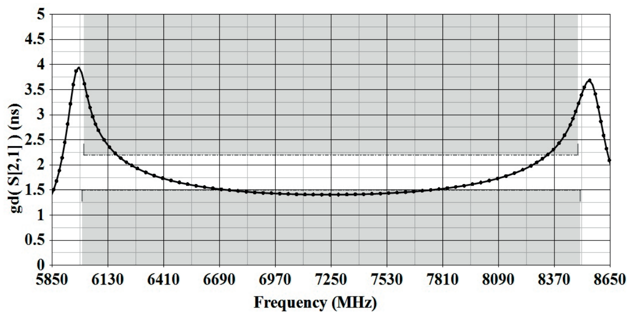


Fig. 8. BP Filter's GTD

The proposed UWB BPF is a complete unit of the UWB communication system transmission part with wave impedance of 50 Ohm. The filter selects and passes the input signal with the maximum EIRP value –41,3 dBm/MHz, according to the requirements of the ETSI mask.

Fractal UWB Antenna Design

Antenna's structure. The development of a new UWB antenna on the basis of fractal technology is described in this Section. The return loss S_{11} will be the cost function:

$$S_{11} < -10 \text{ dB if } \Delta f = 6 \ldots 8{,}5 \text{ GHz}. \quad (4)$$

It is known that circle structures can provide wide frequency band, construction simplification, small size and cost reduction in manufacture, so the circle monopole was chosen as a basis element, which size is equal to the quarter-wave monopole of the desired band: radius of the radiating element r = 12 mm, feeder length $L_f = r$, and all the other parameters are shown at Fig. 9. It will be the zero iteration of the fractal antenna.

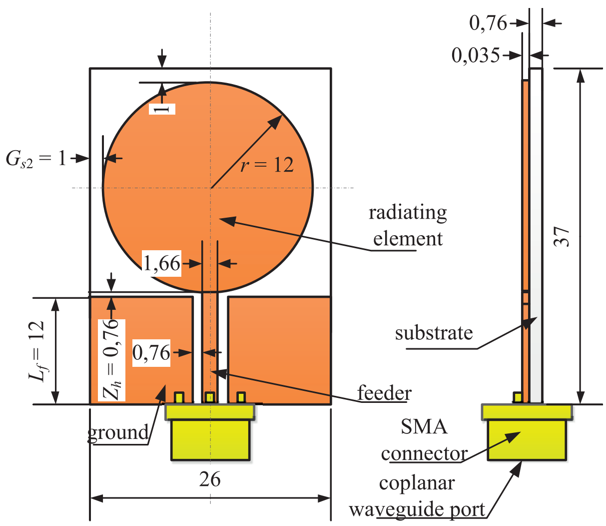


Fig. 9. Antenna's zero iteration

Dielectric substrate Rogers RO4350 1oz 30 ED 30 mil with thickness T_s = 0,76 mm, 3,48 ± 0,05, tg δ = 0,004 is a base, on the front side of which radiating element, feeder and ground are located. Antenna is supplied with coplanar waveguide, SMA-connector and perpendicular coplanar waveguide port. Feeder width is calculated for providing matching with wave resistance Z = 50 Ohm.

Fractal technology was applied for shaping the antenna structure in the way that provides miniaturization. This will also let us study radiation characteristics dependence on scale factor δ and iteration level. The fractality consists in special method of elements packaging: the next iteration is formed by placing the circles of smaller radius in the previous iteration elements. The scale factor δ defines the size multiplier of the adjacent iterations. This process for δ = 2 is shown at Fig. 10.

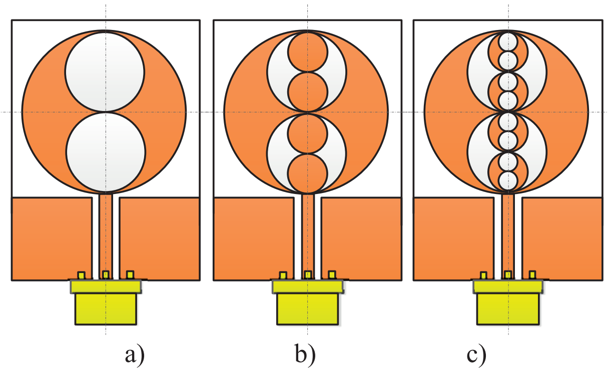


Fig. 10. Fractal antenna's iterations (δ = 2): a) zero order; b) first; c) second

Fig. 10. Fractal antenna's iterations (δ = 2): a) zero order; b) first; c) second

The main idea of simulation is that at each step one parameter is being changed, while the others are fixed, and the best characteristic is chosen at the end according to the rule. If the difference in the band, where the shelves (plane parts of the graph between two resonances) are higher than –10 dB, is not much, so you should choose that characteristic, which shelves are lower in the working band, since during optimization the first mentioned shelves will be removed, and the second shelves will be much lower. Antenna was calculated and simulated with «CST Microwave Studio».

Scale factor and iteration level study. S_{11} changing dynamics, depending on iteration level, is shown at Fig. 11 for δ = 2, and at Fig. 12 – for δ = 3. Each iteration level is characterized with one additional resonance frequency. And starting from the 2nd iteration the changes in characteristics behavior are less noticeable. According to the rule the 3rd iteration curve was chosen for both values of δ.

It's interesting that starting from δ = 3, the curves behavior becomes smoother and more sloping, the number of resonances is constant, and δ growth leads to S_{11} increase in even bands and decrease – in odd bands.

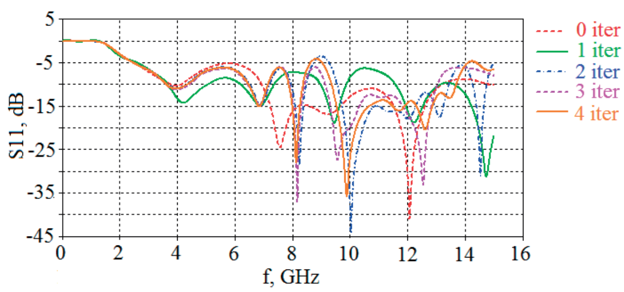


Fig. 11. S_{11} dependance on iteration level (δ = 2)

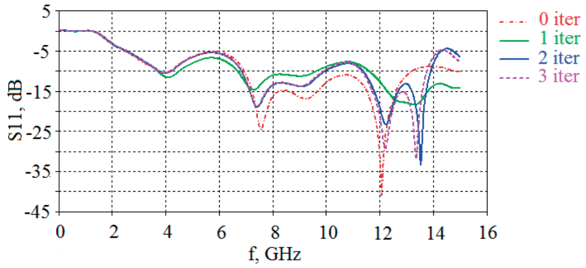


Fig. 12. S_{11} dependance on iteration level (δ = 3)

Considering S_{11} dependence on scale factor, changing in the range of 2 … 6, within the 1st and 2nd iterations it was found the optimal value δ = 6 for both cases (Fig. 13-14).

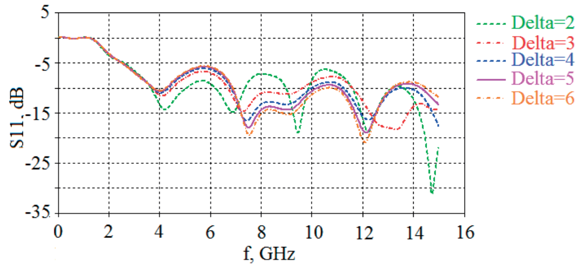


Fig. 13. S_{11} dependance on scale factor for 1st iteration (δ = 2; 3; 4; 5; 6)

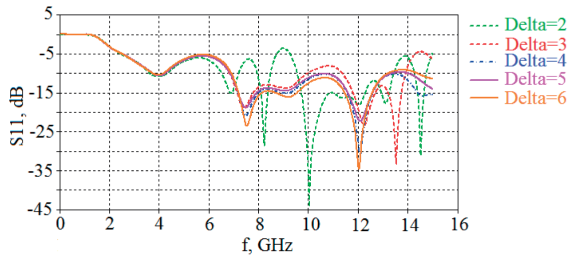


Fig. 14. S_{11} dependance on scale factor for 2nd iteration (δ = 2; 3; 4; 5; 6)

Comparing these four curves, chosen at each step, the most perspective is that, which is corresponding to the 2nd iteration, δ = 6 (Fig. 15). The operating bands are 3,825÷4,242 GHz and 6,969÷13,2 GHz.

A. Optimization

On the this stage the developed fractal UWB antenna will be modified for enlarging its work band by changing the parameters, described in Table 2 and also shown at Fig. 9.

Table 2. Antenna's optimized parameters

Name	Descri-ption	Changes range, mm	Initial value, mm	Final value, mm
ΔL_f	Feeder length increment	ΔL_f =[-6;-5;… +6]	0	+4,0
Z_h	Horizontal gap	Z_h=[0,1;0,2;… 0,76]	0,76	0,76
G_{s2}	Substrate horizontal gap	G_{s2} = [0,5; 1;…6]	1,0	5,0

The optimization includes three steps; on each of them, one parameter is being changed, while others are fixed.

Step 1. The first parameter – feeder length L_f. Its increase leads to resonances movement to low-frequency (LF) band, shelves falling in the 1st and 3rd bands and shelf growth – in the 2nd band. When ΔL_f = +4 mm the 1st shelf level is one of the lowest, the 2nd shelf – lower than -10 dB, so the final feeder length will be 16 mm.

Step 2. The second parameter – horizontal gap Z_h. The bigger Z_h, the lower the shelves in the 1st and 3rd bands, so the optimal value Z_h = 0,76 mm.

Step 3. The third parameter – substrate horizontal gap G_{s2}, which also defines the ground change. When the ground is wider, the resonances move to the LF band, the shelves get lower, even resonances get deeper. The smallest value of G_{s2}, which provides UWB band, is 5 mm.

Fig. 21 shows the curves, reflecting S11 changes at each step, confirming the reasonableness of every next action. The calculated antenna's parameters are presented in Table 2.

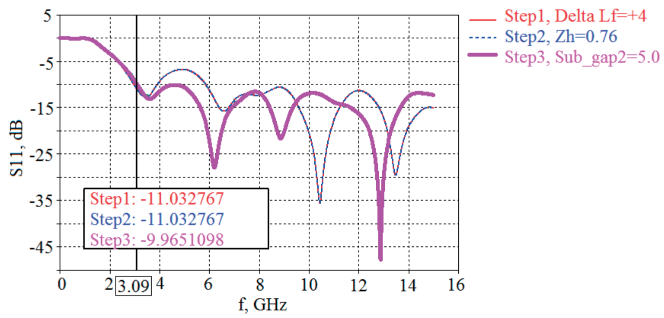
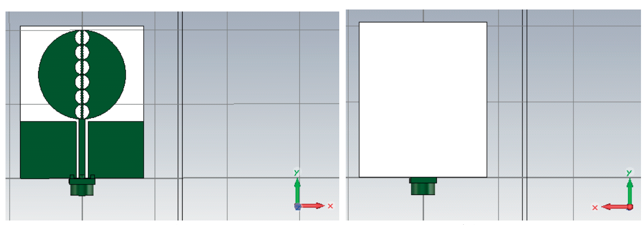


Fig. 15. S_{11} parametric changes

The antenna's final operating band is 3,09 … 15 GHz, the dimension – 34×41 mm² (Fig. 16). The radiation pattern is shown at Fig. 17.



a) b)

Fig. 16. Developed and optimized fractal antenna: a) front view; b) rear view

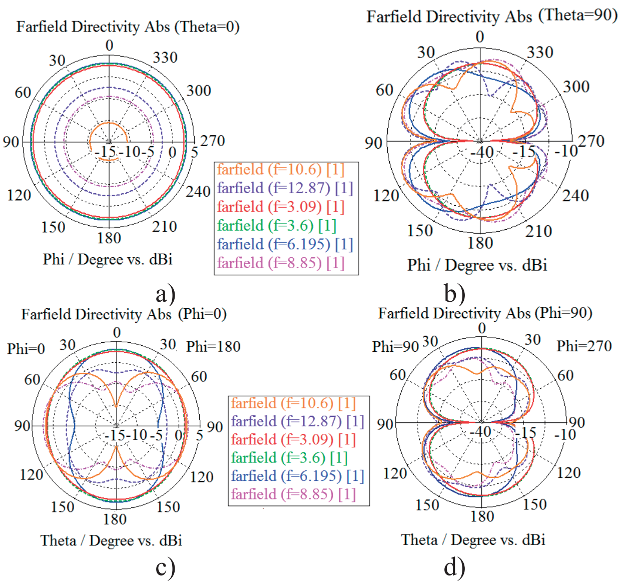


Fig. 17. Antenna's radiation pattern: a) F(φ), $\theta = 0°$; b) F(φ), $\theta = 90°$; c) F(θ), $\varphi = 0°$; d) F(θ), $\varphi = 90°$

Conclusion

The development of two planar microstrip devices for UWB signal transformation, taking into account ETSI mask, was proposed in this paper – the pulse shape filter and fractal UWB antenna. The pulse shape filter provides band pass behavior with the sharp rejection outside the band 6 … 8,5 GHz. It also has good results in its parameters VSWR and group time delay adequacy. It should be noticed that such interdigital microstrip filter with the above mentioned parameters and characteristics, even if it seems to be simple, wasn't developed for the ETSI mask before.

The antenna also radiates in the same band, so they are matched with each other and also to 50 Ohm impedance. The antenna was also studied from «fractal» point of view. It was found out that the number of resonance frequencies grows with the iteration level increase, and the scale factor influence consists in smoothing S_{11}, while δ is getting higher. So finally the 2nd iteration antenna with $\delta = 6$ was optimized for providing the band 3,09 … 15 GHz. The antenna and filter are characterized with compact size, low profile and weight, easy manufacturing. Their application in UWB systems can ensure interference suppression with existing and future wireless technologies.

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ПРОЕКТИРОВАНИЕ СШП ФОРМИРУЮЩЕГО ФИЛЬТРА И АНТЕННЫ ПОД ТРЕБОВАНИЯ СПЕКТРАЛЬНОЙ МАСКИ ETSI

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В статье проведено моделирование основных блоков СШП системы связи, отвечающих за формирование сигнала, соответствующего ограничениям спектральной маски ETSI: фильтра формы и планарной антенны. Предложенная микрополосковая структура фильтра на основе фильтра Чебышева одиннадцатого порядка обеспечивает полосу пропускания 6 … 8,5 ГГц, соответствующую основному «окну» спектральной маски ETSI. Размеры фильтра – 27×16 мм^2. В основу структуры планарной СШП антенны положена фрактальная технология, что позволило обеспечить согласование в рабочем диапазоне 3,09 … 15 ГГц при сохранении малых размеров (34×41 мм^2), свойственных СШП-диапазону. Оба устройства выполнены из одного материала и могут быть реализованы на одной печатной плате. Данное преимущество приведет к уменьшению затрат на изготовление и увеличению эффективности всей сверхширополосной системы связи в целом.

Ключевые словаs: сверхширокополосная связь; спектральная маска ETSI; формирование импульсов; фильтрация; фрактальная антенна.

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ОПРЕДЕЛЕНИЕ НЕЗАНЯТЫХ ЧАСТОТНЫХ ПОДДИАПАЗОНОВ ПО СЖАТЫМ ИЗМЕРЕНИЯМ

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Рассмотрена задача оценки незанятых частотных поддиапазонов в анализируемой полосе частот полностью в цифровой форме. Подобная задача представляет значительный интерес в системах когнитивного радио. Разработаны два алгоритма оценки, основанных на классическом байесовском подходе и парадигме Compressive Sensing. Показано, что применение разработанных методов позволяет добиться существенного уменьшения количества выполняемых в цифровом процессоре операций при несущественном ухудшении точности соответствующих оценок.

Ключевые слова: когнитивное радио, Compressive Sensing, отношение правдоподобия, смещение оценки, рассеяние оценки.

Введение

Развитие микропроцессорной техники в последние десятилетия привело к тому, что операции обработки сигналов все чаще реализуются в цифровой форме. Причем оцифровка сигналов может осуществляться непосредственно на несущей частоте. В этом случае аналого-цифровой преобразователь подключается непосредственно к выходу антенны через согласующий усилитель. Преимущество такого построения заключается в том, что при этом исключаются операции преобразования частоты, детектирование сигналов с выделением их огибающей, что сокращает энергетические потери, повышает чувствительность приемной системы и упрощает аппаратурную реализацию [1].

Рассмотрим возможность применения полностью цифровой обработки в системах когнитивного радио (Cognitive Radio) [2], в которых обязательной процедурой является исследование определенного частотного диапазона с целью поиска в нем «свободных» частотных интервалов. Для этого заданный частотный диапазон $[F_{\min};F_{\max}]$ разбивается на N_f подынтервалов и в каждом