Impact of Photonics on the Education of Electrical Engineering Subjects

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Abstract: - Paper deals with a reality of penetration of photonics into electronics and problems with teaching of the basic problems of photonics in the frame of electrical engineering program study. From our point of view some basic information can be given to students during the study of classical electrical engineering subjects without respect on the next specialization. For study of application of fundamentals and photonic components in systems it is better to introduce special subject photonics.

Key-Words: - photonics, electronics, photon, electron, education, electrical engineering program

1 Introduction

Term photonics arises analogical to the term electronics and reflects the relation between optics and electronics. While electronics includes components and systems where a flux of charged particles, mainly electrons is controlled, photonics works with a flux of photons.

Thorough the considerable overlap of both branches their specialities come from qualitative different properties of electrons and photons. Even if the relation electron - photon is generally used, it is necessary to remind that only qualitative comparison of electromagnetic waves in the radio and optic region should be completely correct. We must have this fact in our mind during the next analysis where this comparison of electron – photon will be used.

Electronics and photonics have been the two relative separately developing branches. Progress of electronics was typical by the continual application of physical knowledge about an electricity, magnetism, theory of materials and the different mathematical resources to the development of components and systems. Expansion of technological possibility has been important during their realization and all the time considerable penetration of electronics to the all branches of human activity and there from by return resulting demand on development of the electronics. The development of optics has been focused on the design of optical sources, detectors, transmission media, and their technological progress.

A realization of the first lasers enabling effective modulation of optical beam, and after that also electroluminescent sources based on the PN junction, enabling direct modulation of optical beam by means of electrical signal, have been the break in the development of optics and subsequently also electronics. Other requirement on the development of optical detectors and transmission media - optical waveguides is connected with these results.

In these rudiments some optimistic forecasts of progress of electronics and photonics have appeared. Regarding to the propagation of photons by the velocity of light and their electric neutrality, the ideas about substitution of electrical coupling by the optical to obtain very fast, on the electromagnetic disturbance resistant components were actual. Technological progress of electronics shows that possibilities of electronics are not yet exhausted, and simple solution made by substitution of electrons by the photons does not lead to the effective solution. The limits are given not only by the fact that photon flux is generated by the electronic components, but for effective application of idea, operation with photon flux must be solved. This fact does not mean that after exhausting of technological and physical possibilities of electronics by the reaching of physical limits, the photonics will not be used in this meaning.

2 Characteristics of photonics

Present photonics can be characterized by the physical and technological progress in some spheres as follows:

- In the area of optical sources there are available semiconductor sources in different alternatives of PN junction, which enable direct modulation of optical beam by the electric signal for wide spectrum of wavelengths. Important place have lasers based on the materials of different states, whose coherent optical radiation enables realization of time and spatial modulation and by this way to increase volume of transmitted or processed information. Possibilities of application of other physical principles increase for imaging components.
- Design of detectors, based first of all on the PN junction, proceeds hand by hand with the development of sources, mainly for necessary tuning

of wavelengths, in the area of fast detectors. The second group are planar detectors based on the CCD or CMOS structures eventually also PN junctions, enabling scanning of pictures. They find their use in systems of ordinary color scanning or special systems in different spectral regions.

- In the area of communication there are lot of quality fibers and planar waveguides together with number of components of fiber and integrated optics, enabling realization of different operations with optical signal, as modulation, attenuation, selection and addition of signals in the time or wave region.
- Qualitative priority of photonics could be possibility of generation and processing of two-dimensional signal. This fact of course requires research and development of spatial modulators and recording environment. Realization of two-dimensional Fourier transform by the relative simple optical system gives possibilities of 2D optical signals processing in the different branches of research and technology. Holographic record of optical signal enables record of phase, applied for processing of images and also for recording of 2D Fourier transform, or other mathematical operations with 2D signal, respectively. We can wait that this area is one of these, where photonics will affect information processing systems in the future.
- We cannot omit development of sensors and sensor systems based on the photonics. With application of transformation of physical quantity on the parameter of optical environment sensors enable to scan a wide scale of physical quantities, frequently without any contact. By using of fibers as sensor elements is possible to realize scanning from high distance or in the big space.

3 Identity and differences of electronics and photonics

If we receive character of signal carrying information (i.e. electrons and photons) as basic differentiation of electronics and photonics, we will find conformities but also differences in approach to the solution of systems of transmission, recording, imaging and scanning of information.

- From the general theory of signal point of view we find the same approach both in electronics and photonics. On solution of practical applications it is necessary to respect differences in possibility of modulation and energetic relations. Mostly we neglect bandwidth of carrier signal in electronics and without any problems realize modulation of amplitude, frequency or phase. Also detection of these signals is without problems. In optical signal domain we cannot usually neglect the bandwidth of carrier spectrum. Reason could be also a type of modulation and possibility to transmit big amount of information in optical spectrum requiring determination of bandwidth for each channel. Extremely strong requirements are for example on the bandwidth of carrier for phase modulation, and it is limiting factor for wider application.
- Also energetic aspect is different. If we compare both signals in the area of electromagnetic waves, where comparison is correct, signals are different from the quantum character point of view. For example we choose energetic quantum in optical region for frequency equals 10^{14}Hz, its value is given as $h.10^{14}$ [J], where h - Planck constant. For radio-frequency waves of 10^{9}Hz, value of energetic quantum is 10^{5} less. At an ability of optical detectors to detect energy of tens photons in optical spectrum, corresponding energy in a radio- frequency area equals to millions of quanta, where it is not necessary to attribute quantum character to the energy, but it could be considered as continuous flux. A quantum noise, which plays important role in the detection of small signals, it is specificity of optics in this case.
- Difference in generation and detection of optical and electrical signal is striking. While for electronics it is typical that generation and detection are realized in macroscopic systems, for optical region these processes are realized in the level of micro-particles, i.e. atoms or molecules. This difference comes from different wavelength of generated or detected signal. Close connection of electronics and photonics we find in the narrow sequence of electrical circuits on the systems of generation and detection of optical signals.
- In the area of data transmission two different parts are to be considered. For communication in the free space we must calculate with strong difference between attenuation of signal in radio and optical region detrimental to optical signal. On the other side we can reach high directivity using optical signal, unavailable with radio-frequency signal. For communication in waveguide structures, in principle it is problem of transmission of electromagnetic energy. At electronic systems it is bounded with transmission of free electrons in conducting structures, at photonic systems in dielectric structures combined with movement of fixed charges and polarization of dielectric.
- From the signal processing point of view, electronics enables processing of one-dimensional signals in time, photonics enables processing of two-dimensional signals in time. For both cases we can use practically the same mathematical apparatus, from practical point of view there it is marked

difference in realization of both approaches. Preference of photonics incumbent in possibility to process parallel big amount of information is at the expense of considerable realization requirements. It is valid mainly for spatial modulators and recording materials, enabling modulation and record of optical signal including the phase. Application of optical components for realization of operations with optical signal is also significantly different from electronics.

4 Photonics in system of electronics study

Next analysis will be focused on the training in the area of photonics, requiring specific study of physical basics of common, wave and quantum optics and common electrical engineering. We will concentrate on the study of electronics, where photonics is not main branch, but its understanding is necessary with regard to always wider application of photonic principles in electronic systems.

Generally we can divided training of students to the three periods, penetrating each other:

- Fundamentals of mathematics and physics
- Fundamentals of electronics
- Training in the frame of specialization.

Area of fundamental preparation is conservative from the principle point of view. It deals with general problems and fluently is modified to the requirements of era. Area of special preparation works usually with the specific systems, which are applied in given branch, not with general problems of photonics and builds on the previous knowledge. From these statements it flows, that photonics should come most expressive to the system of electronics fundamental preparation, based on the requirements of specialization and also general education. It is clear, that photonic systems as well as electronic systems enter, and they will enter more and more to everyday life.

The area of basic preparation could be divided into parts as follows

- Material and components basis
- General electrical engineering and field theory
- Electronic circuits and systems
- Electronic measurements

In the materials area it is necessary to extend properties and applications of materials in electronics and briefly in photonics. Other intensification of this knowledge is possible to give in study of electronic components, where some problems of photonics are suitable to connect with the principles of components. There are for example properties of PN junction, where except physical properties used for application in electronic components it is suitable to include phenomena and properties used for generation and detection of optical radiation. This connection can contribute to the better understanding of real components properties. For other problems there is more suitable presenting them in special theme. An example can be optical amplifiers and lasers, where it is possible to wide knowledge about PN junction to the laser structure, special detection structures as PIN photodiode, avalanche photodiode, heterogeneous structures, quantum wells and optical modulators. Surface detectors, where except of physical principle, also mechanism of reading from partial elements is important, require some special part.

Optical waveguides are very important area including fibers, integrated structures and components based on these principles. Accent should be put on the basic mechanisms of optical wave propagation with the sequence on the parameters and properties describing these mechanisms. Sequence on the electromagnetic field theory depends on the time order of subjects.

In the area of common electrical engineering, eventually fundamentals of circuits it is necessary to choose a careful access. It is possible to place a problem of photon coupling and its importance for galvanic separation of the circuits, but unsuitable interpretation of relation between the electron and photon coupling can rather blackout problematic of some phenomena.

Different situation is in the area of electromagnetic field theory, which creates the base for solutions of optical waveguides. Possibilities of more detailed solution of waveguide structures depend on the extent of subject. While microwave circuits based on waveguides are specific part of microwave technology, and they are solved in special subjects, some basic theory of optical, dielectric waveguides should be given as part of field theory subject.

Area of measurement is given generally, with problems of measurement and also with objects of measurement and parameters of measured object. From this point of view we can divide these problems as follows:

- Measurement of parameters and characteristics as experimental evaluation of theoretical knowledge
- Measurement as process and set of measurement systems with their principles and using.

In the area of measurement of parameters and characteristics it is continuous process in the course of education, for example measurement of parameters and characteristics of optical sources and detectors, modulators, fibers etc. Also we can include some manipulation with components and systems i.e. fibers, or demonstrations of components and systems properties.

To the second group we can include theory and practice of measurement. This requirement is given by the extending group of measuring systems for measurement of different characteristics and parameters of optical

radiation, components and systems. Complexity of insertion of these problems to the system of classical electronic measurements comes from qualitative difference between fluxes of electrons and photons, and from the whole matter of measurements. Difficult compatibility would be also in the cases of microwave and optical measurements, where substance of measurement is electromagnetic wave.

From the previous requirements on an insertion of photonics to the particular parts of electronics it follows that most simple is insertion of photonics to the materials and components parts. These parts come from general physical knowledge, in addition number of principles are going for example from quantum theory, the common for fundamentals of electronic and photonic components, based on the solids. In the level of physical base we can explain also waveguides structures accordingly to previous knowledge.

In the part of general electrical engineering we can suitable evoke some problems of photonics, while in the area of field theory it is possible to collect problems of propagation. First of all we can accent the same principle of radio and optical waves with enforcement of their quantitative differences from the energetic-quantum point of view.

Relative complicated could be insertion of photonics to the part of electronic circuits and systems. Without any problems it is possible to take electrical and optical signal from the signal point of view, with accent on the application of two-dimensional character of optical signal. In the other side mergence of problems of electronic and optic circuits regarding to the different quality of signal carriers i.e. electrons and photons, is probably unsolvable. Forcible insertion of photonic systems could not benefit to both areas despite of some interesting parallels. These questions are better to insert into special subject.

To the similar conclusion we can come also in the area of theory and practice of measurements. Fundamental of photonic measurement is different from electronic, and violent integration should lead to darken of both parts problems. We can apply common theory as theory of uncertainty etc., indeed.

Important part of today photonics is area of optical sensors, because their quantity and quality increase all the time and we can suppose their application in different branches of research a technology. The coupling to electronics similar as for other sensors consists in transformation of optical signal, which is scanning and transmitting medium, to electrical signal. Because of wide spectrum of problems, this part cannot be inserted into the study of electronics.

From previous analysis we can receive the conclusions as follows:

- Contemporary penetration of electronic and optical systems needs inserting of other partial questions of photonics to the subjects of electronic fundament, where it is possible and suitable. Some examples have been done in previous text.
- Insertion of some problems of photonics to some electronics subjects is not ideal with regard to qualitative differences of electronic and optic principles and corresponding systems. The example could be subjects dealing with design of electronic circuits or electronic measurement. From this reason it would be better to insert some subjects inclusive the basic areas of photonics or partial areas according appropriate interest of students, into program of preparation specialists in electronics.

Example of such idea could be subjects as follows:

- Photonics
- Fiber and integrated optics,
- Optical methods of signal processing
- Optical sensors.

There could be of course other modifications.

5 Example of general electrical engineering subject with photonic parts

For all students of electrical engineering branches at University of Defense we have prepared the subject giving students basic knowledge about materials, principles of components, their characteristics and parameters including some basic photonics components [1], [2].

The program of study is as follows (photonics parts are marked bold):

Subject: Electronic components (1st and 2nd terms)

- Materials
- Passive components
- Chemical sources
- Semiconductor diodes
- Bipolar transistors
- Unipolar transistors
- Thyristors
- Manufacturing of integrated circuits
- Analog integrated circuits
- Digital integrated circuits
- AD and DA transducers
- SMD technology
- **Optical radiation, optical signal**
- **Physical phenomena in the opto-electronic components**
- **Optical sources**
- **Optical modulators**
- **Optical detectors**
- **Surface detectors CCD, CMOS**

- **Optical fibers**
- **Fibers in communication and sensor applications**
- **Opto-electronics function blocks**

This subject is taught in program of study during the first and second term in the whole length of 90 hours. The photonics parts from this have amount of 20 hours. We have also experiences with education of two special subjects, which have been taught as facultative for some branches of faculty according previous 5-year program of study [3], [4].

6 Conclusion

In conclusion we can add, that hundreds of different courses exist in present time at the world universities with different range from area of photonics and optics [5]. But these courses are mostly focused on the training of pure photonics and optics specialists, in some case in specific areas. The aim of this analysis has been to think about training of specialists in electronics, who will meet more and more photonic components and systems in the electronic equipments.

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