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Design studies for the beam position monitor (BPM) front-end electronics of the Turkish accelerator and radiation laboratory in Ankara (TARLA)

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Abstract: A beam diagnostics system is vitally important to operate all accelerator-based facilities. The system provides information about beam characteristics and enables requested beam parameters to be achieved. The main parameters, such as beam energy, current, emittance, and beam position, must be diagnosed and controlled during the operation of an accelerator. Beam position monitors (BPMs) are an essential tool for diagnosing a system of accelerators. They are used to define the position of the beam traversing through the beam pipe at relativistic speed. These tools can be used to achieve the required beam quality as well as protecting the entire system against any beam loss or radiation damage. In this study, we present the bases of BPM front-end electronics designed for the Turkish accelerator and radiation laboratory (TARLA) facility, which is a linear electron accelerator proposed to drive a free electron laser.

Key words: Beam position monitors, peak detectors, radio frequency

1. Introduction

The Turkish accelerator and radiation laboratory (TARLA) facility has been funded by the Ministry of Development of Turkey since 2006. It mainly consists of a normal conducting injector, two sequenced superconducting accelerator modules, two optical cavities, and a Bremsstrahlung radiation hall (see Figure 1). Electron bunches are released from a 250-keV thermionic DC gun, transported to the main linear accelerator (linac) via an injector system, and accelerated up to 40 MeV at continuous wave (CW) mode [1].

The facility will mainly operate as an infrared radiation (IR) FEL light source, with a secondary purpose of Bremsstrahlung experiments. In addition, fixed target applications will also be possible at TARLA. The electron beam parameters of TARLA are summarized in Table [2].

In this study, we present the front-end electronics of the TARLA beam position monitor (BPM), which are very important nondestructive diagnostic tools measuring beam position and beam current. BPMs may be designed in various geometries such as button, stripline, cavity, and linear cut that all working on the basis of measuring electrical charge [3]. Cavity BPMs, which have a complex structure, are generally used for arrival time monitoring as well as beam position. Linear cut BPMs are generally used for systems that have long bunch length in the rage of ns. Both stripline and button-type BPMs are often used in linear electron accelerators with short bunches. However, stripline BPMs require long installation space because of the length of the antennas. Due to the limited space for BPMs on TARLA beamline the button type of BPMs that have

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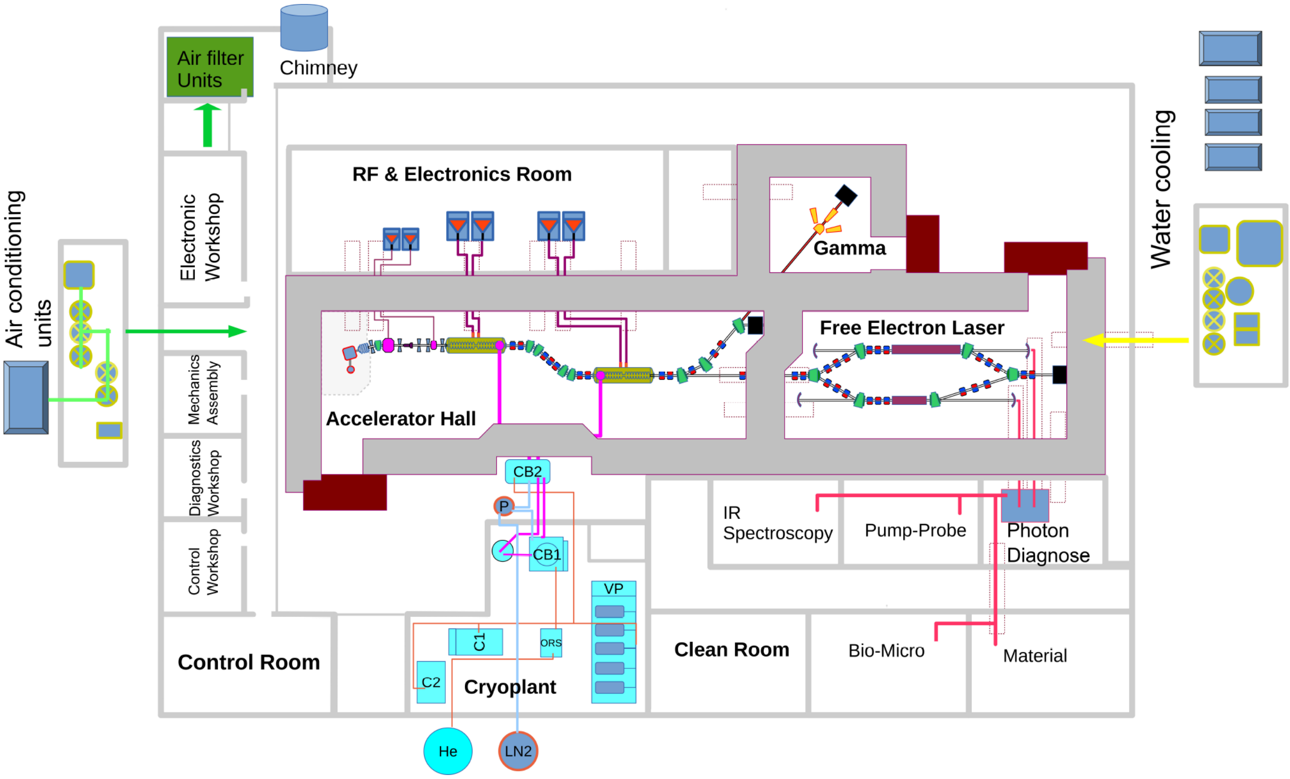


Figure 1. TARLA layout.

Table. Electron beam parameters of TARLA.

Parameter	Unit	Value
Beam energy	MeV	15–40
Max. average beam current	mA	1
Max. bunch charge	pC	77
Horizontal emittance	mm.mrad	< 15
Vertical emittance	mm.mrad	< 12
Longitudinal emittance	keV.ps	< 85
Bunch length	Ps	0.4–6
RMS energy spread	keV	< 100
Bunch repetition rate	MHz	13
Macro pulse duration	μs	50→CW
Macro pulse repetition rate	Hz	1→CW

4 identical electrodes (antennas) in a circular mechanical system (see Figure 2) are proposed to be used at TARLA [4].

As the electron beam travels in the BPM, the electrical charges induced by the electrical field of the electron beam are measured through antennas. In order to determine the beam position precisely, the electrical charge has to be measured accurately. Depending on the position of the beam, each antenna may be induced with different electrical charges. In other words, the electrical potential on the antennas $V_i\,(i = ABCD)$ to be measured can vary from one antenna to the other depending on the position of the beam. The ratio of signal

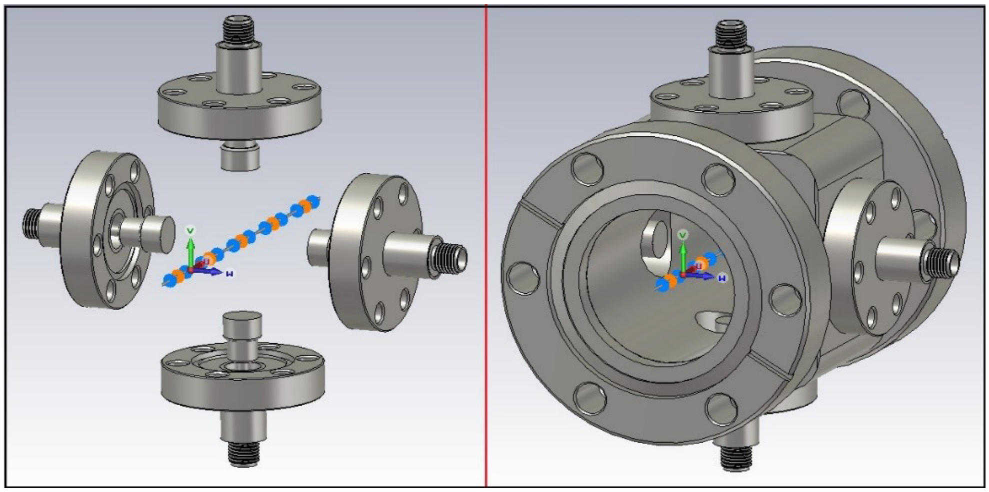


Figure 2. Button-type TARLA BPM.

amplitudes is used to find the beam position [5]. The horizontal and vertical position of beam are expressed as

$$x = C\left(\frac{V_A - V_B}{V_A + V_B}\right) \tag{1}$$

$$y = C\left(\frac{V_C - V_D}{V_C + V_D}\right), \tag{2}$$

where x and y are the transverse beam positions and C is the half radius of the BPM. Although it is possible to measure the signal coming from an antenna by oscilloscope, it is inconvenient for an accelerator as the control system of an accelerator requires fast data that will be manipulated digitally in another process. However, the use of an oscilloscope would increase the cost. For instance, the TARLA diagnostic schema requires more than 40 BPMs; thus one would need 40 high resolution ($>$2 GHz) oscilloscopes. In order to have flexibility on measured data and to reduce the cost, customized front-end electronics are designed according to the requirements of the TARLA operation.

A button-type BPM has been manufactured according to the TARLA requirements. Figure 2 shows the 3D model of the manufactured BPM, which has an inner diameter of 28 mm and antenna diameter of 5 mm.

2. TARLA BPM front-end electronics

In order to analyze and define the signal coming from the antennas of the TARLA BPM, the test setup shown in Figure 3 has been installed. To simulate the beam passing through we have used a wire located on the axes of the BPM. The wire is excited by a fast pulse generator that produces pulses with 60 V amplitude and 450 ps width (full width at half maximum (FWHM)). The pulse generator is triggered by an external signal generator. To adjust the average current passing through the BPM we have installed a step attenuator at the exit of the pulse generator. The pulses are terminated at the end of the wire.

Figure 4 shows the pulses generated by the pulse generator. As seen in the figure, the pulses have Gaussian shape with 450 ps bandwidth and 77 ns repetition rate. Figure 5 shows the probed signals coming from the BPM's antennas. As seen in the figure, the time structure of the excitation signal is conserved; however, due to the physics of BPMs, the amplitude is reduced while reflected signals are added as noise to the signal.

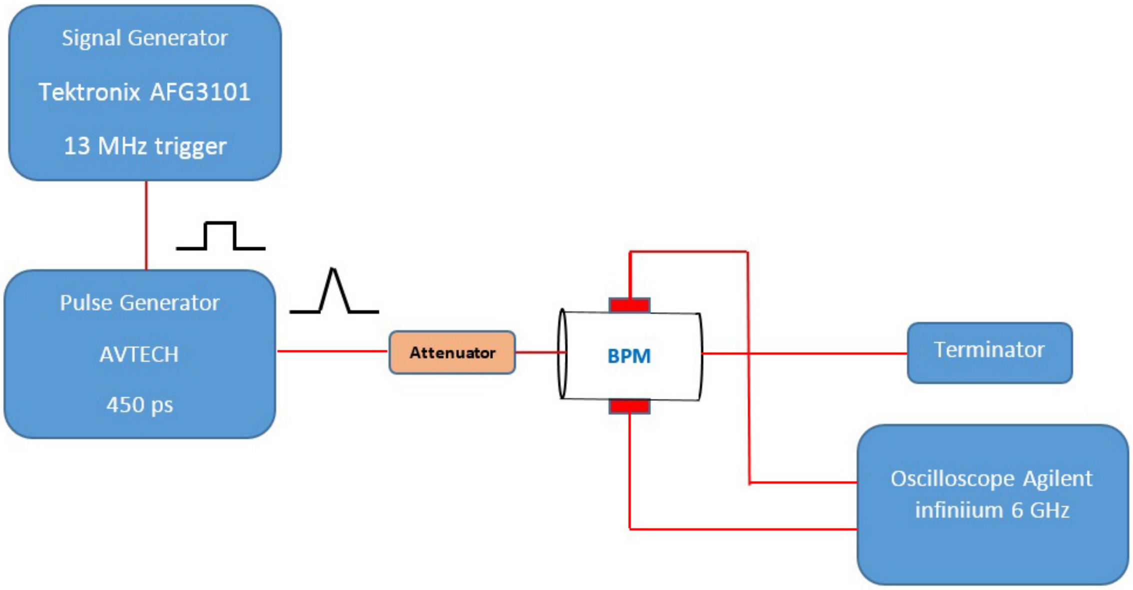
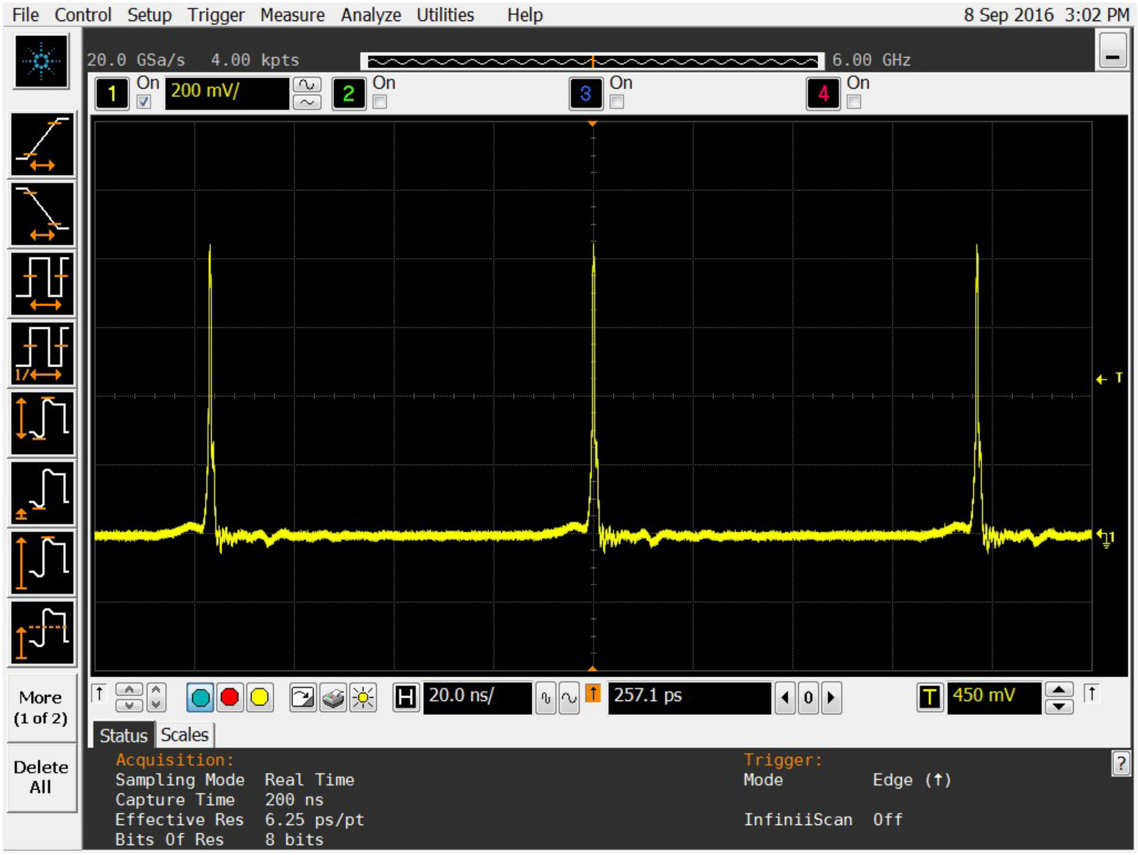


Figure 3. BPM test setup for signal characteristics analysis.



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Acquisition:                              Trigger:
Sampling Mode   Real Time                 Mode         Edge (↑)
Capture Time    200 ns
Effective Res   6.25 ps/pt                InfiniiScan  Off
Bits Of Res     8 bits
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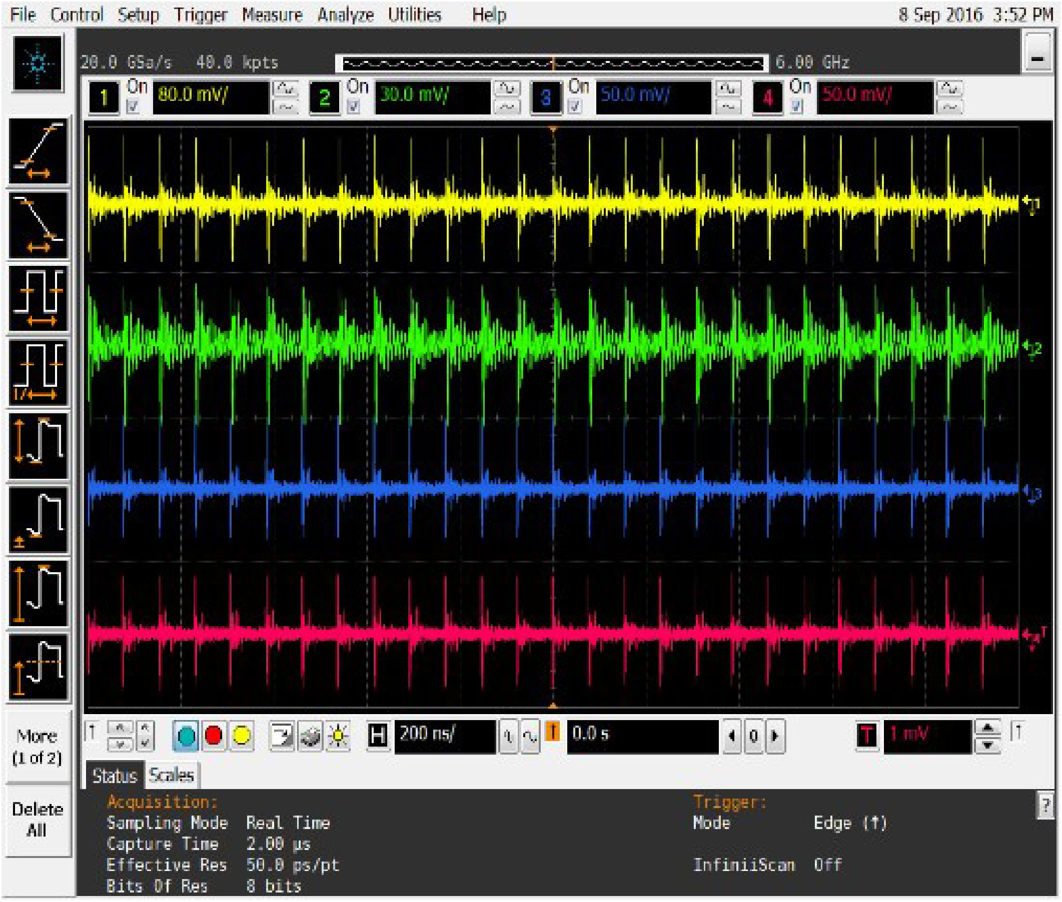
Figure 4. Pulse signal on wire.

One of the challenges of BPM setups is to detect and digitize those fast, low amplitude analogue signals coming from BPM antennas. As a first stage, the induced voltages on antennas are amplified by means of



Acquisition:
Sampling Mode Real Time
Capture Time 2.00 µs
Effective Res 50.0 ps/pt
Bits Of Res 8 bits

Trigger:
Mode Edge (↑)
InfiniiScan Off

Figure 5. Signals at BPM antennas.

broadband pre-amplifiers for better signal processing. Then low pass filters are used to minimize the noise in the signal. Eqs. (**??**) and (**??**) are electronically proved via splitter and combiner circuits. For this purpose, signals acquired from the oscilloscope are saved in text format to be processed by MATLAB. The block diagram of the process is shown in Figure 6.

The output of each simulation step is shown in Figure 7. Consequently, in order to find the position of the beam on the x-axis, signal differences and as well as the total signal are measured.

Although the time structure of the signals does not change after the process as shown in Figure 6, the signals are still fast for digitalization. However, since we are only interested in defining the transverse position of the beam, peak amplitude of the signals have to be measured precisely and, as a result, the time structure of signals can be discarded. On the other hand, if one needs to measure the longitudinal position of bunches, the time structure of the signals must be taken into account.

To measure the peaks of the signals, we propose to use the well-known peak-detector circuit, which is frequently used for digitization processes. The peak detector circuit simply consists of a diode and a capacitor (see Figure 8). This circuit converts peak values of the input signal into direct current (DC) [6].

The circuit in Figure 8 has two challenges in practice. The amplitude of the measured signal has to be higher than the forward voltage (V_f) of diodes and the discharging time of capacitors has to be more than the time between two peaks. Therefore, the amplitude of the probed signals through the antennas are pre-amplified

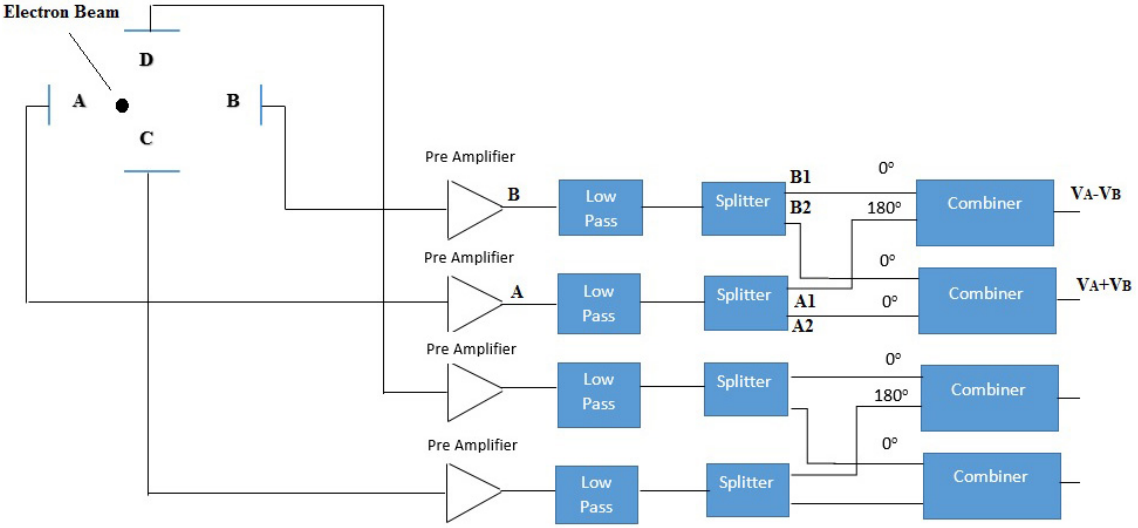


Figure 6. Circuit to get signal differences and total signals.

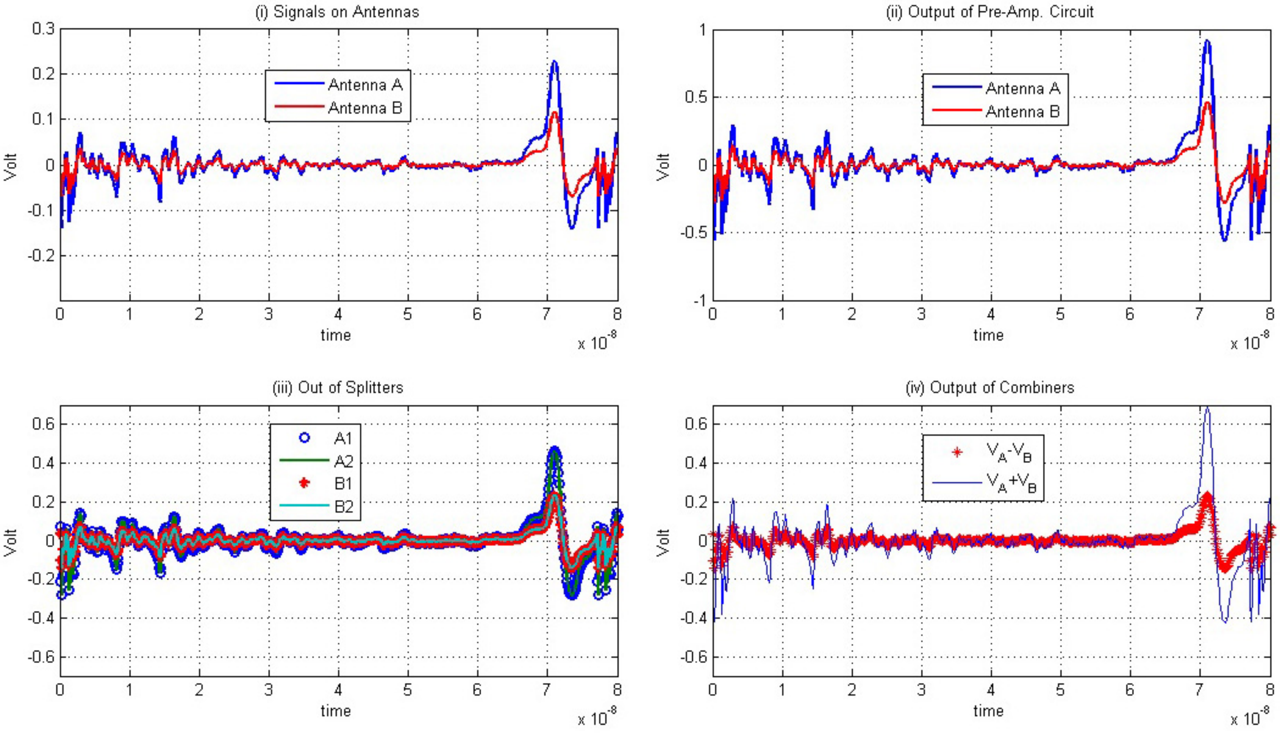


Figure 7. Signal processing steps: i) The antenna signals, ii) Output of pre-amplifier, iii) Output of splitter, iv) Output of combiners.

to higher values than the forward voltage of the diodes (see Figure 6) and the discharging time of the capacitor is set by a resistor.

The BPM electronics based on compensated diode detectors, which was developed at CERN [7], is improved and adapted to the TARLA diagnostics system. The designed peak detector circuit has been simulated with ORCAD.

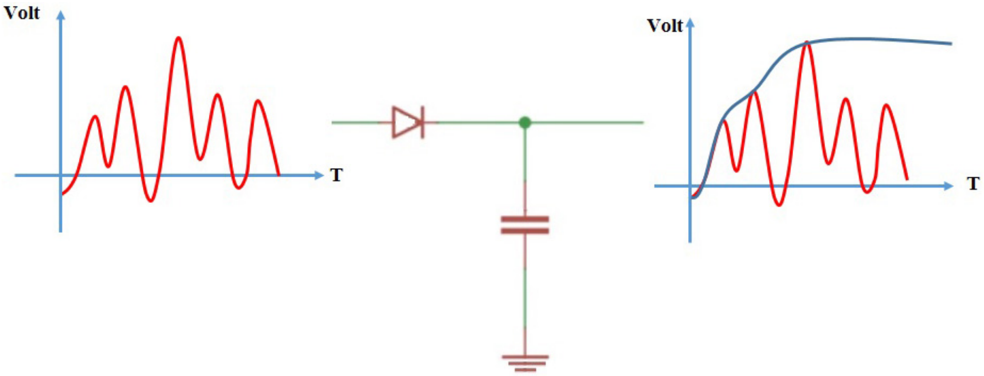


Figure 8. Peak detector circuit.

Depending on the position of the beam, the output of Figure 6 may be either negative or positive. However, the compensated diode detectors developed at CERN can only be used for positive peaks. In order to detect negative signals, we have combined positive and negative peak detectors into an integrated circuit (see Figure 9).

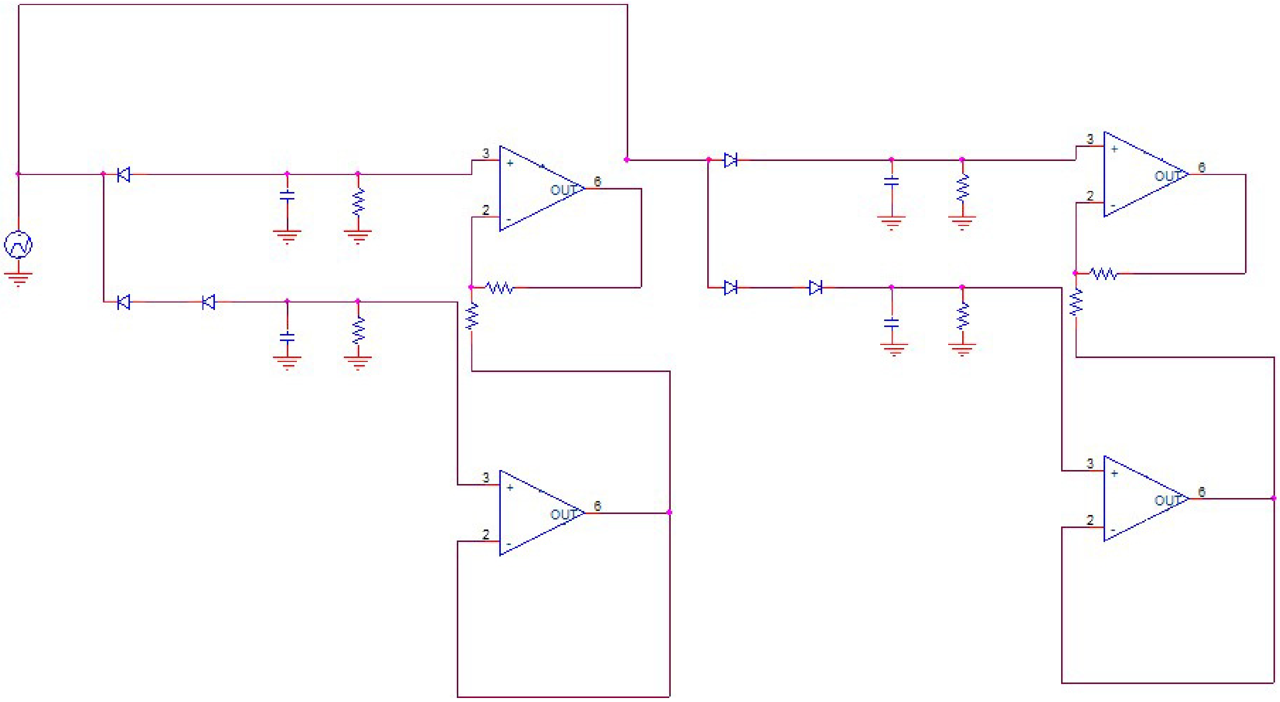


Figure 9. Combined peak detector circuit.

Figure 10 shows the negative and positive peaks generated at the output of the circuit given in Figure 6. Peaks measured by the circuit are given in Figure 8. As can be seen in Figure 9, the circuit detects both negative and positive signals. The peaks are detected within 300 ns. The output signals of this circuit can be measured by a simple multimeter.

As a result of signal processing and simulation, it is proved that fast changing beam signals can be measured by simple and cost effective circuits. In addition, as can be seen in Figures 5 and 10, the oscilloscope

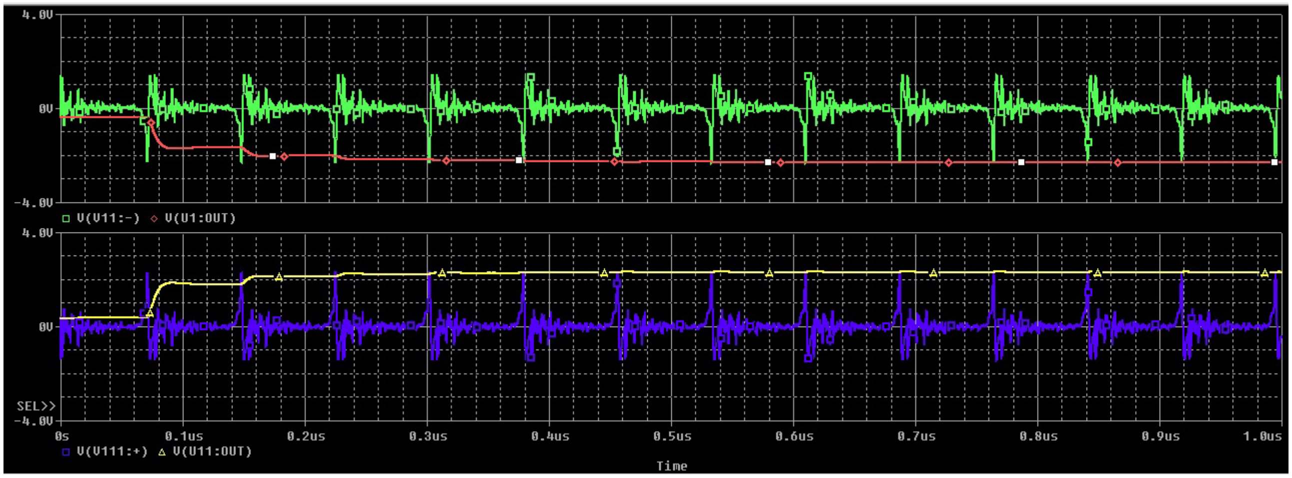


Figure 10. Output of negative and positive peak detector.

results coincide with the results of the previously mentioned signal processing and simulation in terms of signal amplitude.

3. Conclusion

A simple, robust, and cost effective BPM front-end electronics system is designed and developed for the TARLA facility that also can be used in future relevant projects in Turkey, like the 3 GeV synchrotron facility [8]. It is possible to analyze output signals of this circuit via simple measurement instruments. Furthermore, this front-end electronics system is also functional for different diagnostics tools, like beam transformers, beam loss monitors, and optical transition radiation.

With this system, it approximately takes 300 ns to catch the maximum peak value under CW operation, which may also be used for pulsed beam operation with pulse lengths longer than 300 ns.

Acknowledgments

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