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Study of the effect of detector to front-end electronics distance on the spectrometric performances of solid-state detectors

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Abstract: Solid-state detectors are used for charge particles detection and spectrometry with front-end electronics located, usually, next to the detectors. Therefore, in some applications, due to high-level radiation, high temperature and/or electro-magnetic noises (e.g. in nuclear fusion energy experiments, high energy accelerators, etc.) there could be the need to locate the front-end electronics far away from the detector. To solve the problem a *matching sensitive charge amplifier* (MSCA) with AC coupled input was designed by Roberto Cardarelli (former INFN scientist) for measurements at the fusion JET tokamak (U.K.). The prototype, composed of two amplification stages, was "ad hoc" designed for use with Diamond detectors and resulted very reliable. A commercial version of the MSCA was then developed and is now available on the market. Its novelty and main advantage, with respect to the former version, is to be used also with other fast detectors e.g. Resistive Plate Chamber (RPC) with high counting speed and Silicon detectors. The commercial MSCA features input impedance very close to 50 Ohm, which can be matched to a 50-Ohm transmission line. This allows locating the amplifier at variable distances from the detector and up to 100 m. These claimed performances result very interesting for solid state detectors, therefore, up to now a few applications of MSCA are reported in the literature and a systematic study of its performances is missing. In this work, an analysis of the spectrometric performances of Diamond and Silicon detectors coupled to MSCA located at various distances (up to 48 m) from the detectors is reported. Pulse height spectra of a multi-peaks alpha source were measured using MSCA amplifier and compared with those obtained using a standard charge sensitive preamplifier (CA). Then, the effect of the distance between detectors and amplifiers was investigated using standard RG58 and double shielded RG214 coaxial cables. The results are presented and discussed.

Keywords: Electronic detector readout concepts (solid-state); Analogue electronic circuits; Front-end electronics for detector readout

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Contents

1 Introduction

The use of solid-state detectors (SSDs) for particle detection and spectroscopy in some cases could require placing the front-end electronics away from the detectors. These are the cases in which a harsh environment is present, for example, high temperature and/or high radiation level or electromagnetic (EM) noises. Therefore, while detectors able to operate in harsh environments, e.g. Diamond and Silicon Carbide (SiC), are already available it is a matter of fact that there are no electronic devices based on silicon technology that have comparable radiation and temperature tolerance to that of Diamond or SiC detectors. It results thus impossible to locate silicon based front-end electronics in harsh environments. This fact requires to separate, by a certain distance, the detector from its front-end electronics. This can be attained by introducing a proper cable (transmission line) in between the detector and the first amplification stage, without affecting the sensitivity and fast response of the front-end amplifier. This read-out scheme was proposed about fifteen years ago by Roberto Cardarelli (former INFN scientist) who designed and developed a prototype low-noise *fast charge amplifier* (FCA) for neutron detection in harsh environment and to be used at the European JET tokamak in Culham (U.K.). The prototype was specifically designed for use with Diamond detectors [1]. To mention that Diamond detectors characterize for having a very high impedance which reflects in a very low dark current. Other fundamental properties of Diamond detectors are the very fast signal ($<$ 1 ns) and its low amplitude (tens to hundred of µV). All these properties are mainly due to the high band gap (5.3 eV) and the very high mobility of both electrons and holes [2].

Soon after its development, accounting for its characteristics to "match" with the impedance of the transmission line the FCA was re-named *matching sensitive charge amplifier* (MSCA) [3] and so it will be called in the following.

The main feature of the MSCA for particles detector applications in harsh environment (high-radiation, high-temperature) is that the input impedance can be matched to a 50-ohm transmission line, thus allowing to put the amplifier far from the Diamond detector at a distance up to 100 m. The matched input allows neglecting the cable capacitance for the amplifier equivalent noise, since the capacitive contribution of the cable is compensated by its inductive reactance. The MSCA used at JET was purposely developed in bipolar junction technology (BJT) [3]. A scheme of the MSCA is in figure 1.

At JET, the only accessible region for the sensor read-out was 100 m far from the Diamond detector. Connection from the sensor to the amplifier was done by means of a high frequency, super-screened, low

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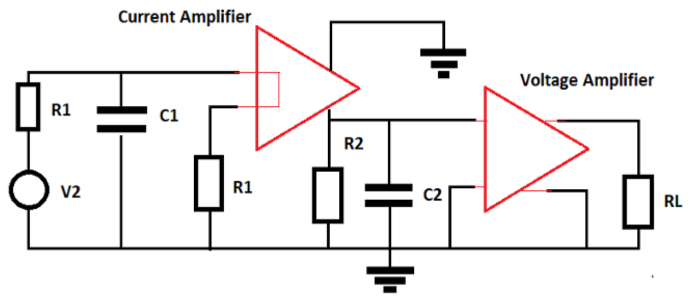

Figure 1. Scheme of the MSCA.

attenuation and capacitance co-axial cable which was already available at JET since it was previously used for other purposes. Two MSCA operated at JET in a very reliable mode for about three years [1, 2].

Subsequently, the CAEN Company engineered the prototype amplifier used at JET and developed a commercial product which is available on the market [4]. The commercial MSCA is an improved version of the MCSA prototype used at JET. This improved version features two amplification stages which are implementing BJT NPN silicon technology and an input impedance very close to 50 Ohm, which must be matched to a 50-Ohm transmission line. In this case, the cable is equivalent to a pure resistor and the capacitive and inductive contribution results automatically compensated [5]. Furthermore, the commercial MSCA was optimized to be used not only with Diamond detectors but also with other very fast detectors such as high counting rate Resistive Plate Chamber (RPC) and thin Silicon detectors with < 1 ns signal rising time [5]. Another important feature of new MSCA is the fast shaping of the signal, down to 12 ns, that allows working at a rate of MHz without incurring in signal pile-up. For further details see [4, 5].

Despite its interesting characteristics and apart the use of the MCSA coupled to Diamond detectors at JET [1, 2] and a test with fast RPC [5], up to now no further applications are reported in the literature for the matching charge sensitive amplifier. A systematic exploitation of the performances of the commercial MSCA when coupled to solid state detectors of different type and with transmission lines of variable distances, is missing.

In this work an analysis of the spectrometric performances of Diamond and Silicon detectors coupled to (commercial) MSCA located at various distances from these detectors is reported. The study was performed using different type of cables (standard RG58 and double shielded RG214 coaxial cables). Pulse height spectra of a multi-peaks alpha source (^{239}Pu ^{241}Am ^{236}Cm) were first measured using MSCA and then compared with those obtained using a "standard" commercial charge sensitive preamplifier (CA) [6]. Then, the effect of the distance (up to 48 m) between detectors and amplifiers was investigated by using the different types of transmission line mentioned above. The various measurements and their results are presented and discussed in section 2 and section 3, respectively, while conclusions are drawn in section 4

2 Experimental set-up

The experimental set-up consisted of a three peaks alpha source (^{239}Pu ^{241}Am ^{244}Cm) of 5.55 kBq activity and whose main lines are reported in table 1, one sensitive charge preamplifier, one MSCA and the needed cables (RG58 and double screened RG214 coaxial cables) of different length, as specified below. An oscilloscope LECROY HDO9304-MS with 3 GHz bandwidth and 40 Gsample/s was also used for assessing the measurements and checking the quality of the pulses (noise, reflections, etc.). The data were acquired using a digitizer CAEN 5751 while the bias voltage (HV) for the detectors was supplied using a CAEN DT1470ET. Two solid state detectors were used, a 500 µm thick, 20.25 mm^2 active area Diamond detector from Diamond Detector Ltd. (DDL) company (no longer on trading) and a Silicon detector manufactured by ORTEC company (now ORTEC-AMETEK) with 25 mm^2 active area with 100 µm of depletion depth when using a voltage bias of −100 V. The Diamond detector was operated at HV = −400 V while the Silicon diode was operated at HV = −100 V. The detectors and the three alpha sources were located inside a vacuum chamber (figure 2) since all the measurements reported in this paper were performed in vacuum (about 10^{-6} mbar) at room temperature.

The measurements consisted in the acquisition, by means of the digitizer, of the pulse height energy spectra (PHS) of the three peaks alpha source measured under different detector to front-end electronics distances. The detectors and the front-end electronics were connected using standard RG58 and double shielded RG214 coaxial cables so to evidence the impact of the type of transmission line on the results.

Table 1. Alpha line energy and emission intensity for the used three peaks alpha sources ^{239}Pu^{241}Am^{244}Cm.

Element	Energy (MeV	Intensity %
^{239}**Pu**	5.105	11.5
	5.143	15.1
	5.155	73.4
^{241}**Am**	5.388	1.4
	5.443	12.8
	5.486	85.2
^{244}**Cm**	5.763	23.3
	5.805	76.7

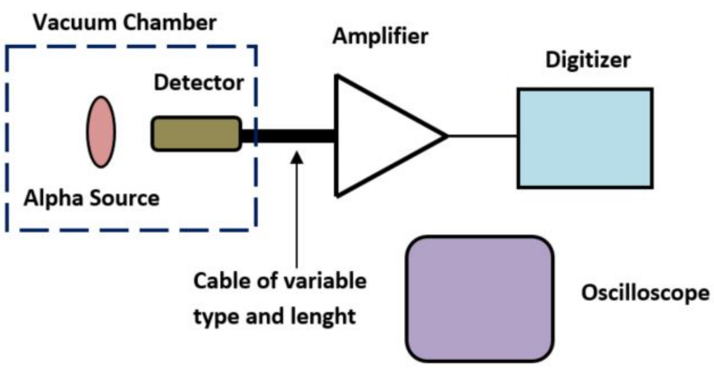

Figure 2. Layout of the experimental set-up.

In the specific, the Diamond and Silicon detectors were connected first to charge sensitive preamplifier and then to MSCA by mean of the already mentioned transmission lines. Thus, PHS were recorded using the same connecting line but using different detectors and were compared between them, as discussed here after. Table 2 summarizes the performed measurements.

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Table 2. List of measurements performed with Diamond/Silicon detector with the different transmission lines.

	CA	**MSCA**
1	20 cm RG58	20 cm RG58
2	2 m RG58	5 m RG58
3	24 m RG214	24 m RG214
4	48 m RG214	48 m RG214

Last, but not least, we mention that thanks to the use of the digitizer it was also possible to save the wave forms produced by the Silicon and Diamond detectors under the various working conditions. Some of the recorded pulses were used for studying the impact of front end electronics and cables on the signals produced by the detectors, as discussed in section 3.

2.1 Measurements using Silicon

A first series of measurements was performed using the Silicon detector. A reference PHS was recorded using the *charge sensitive preamplifier* connected to the detector through a 20 cm long RG58 coaxial cable. The other PHS were recorded just changing the length and type of the transmission line (see table 2). The results obtained with the silicon diode detector are shown in figure 3. To note that the measurement with a 2 m long coaxial RG58 cable was not possible because of the high level of noise introduced by this cable. This is consistent with what is usually reported in the manuals of charge sensitive preamplifiers that suggest the location of the detector close ($\leq$ 1 meter) to the charge preamplifier. Therefore, figure 3 shows that the use of RG214 double screened cable seems to overcame this problem at the cost of a (small) reduction of the signal amplitude and of a more pronounced reduction of the energy resolution in terms of full width half maximum (FWHM). We will further discuss this point in section 3.

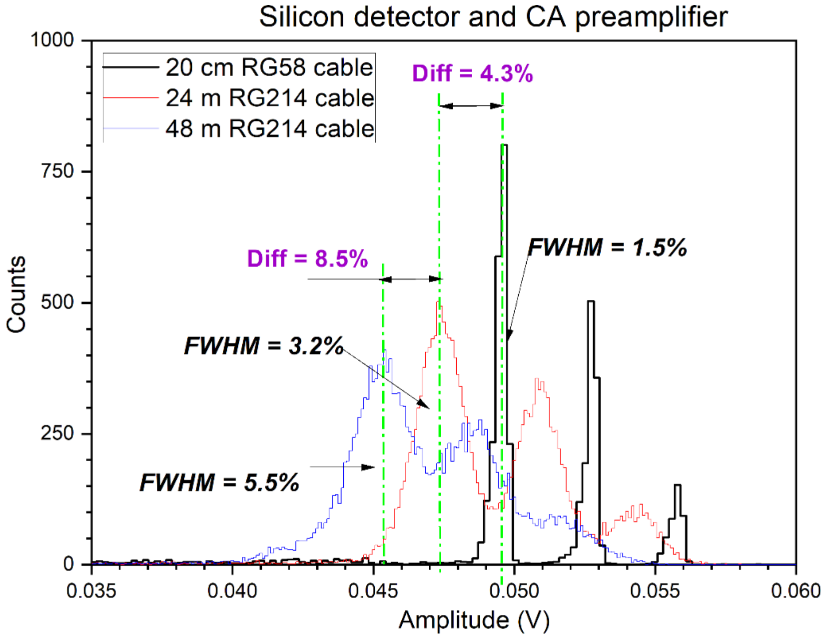

Figure 3. Results with Silicon diode using the charge sensitive preamplifier (CA).

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The same measurements discussed above were then repeated using MSCA. The results are shown in figure 4. In this case, a reduction of the FWHM with respect to the measure with CA is observed already when using 20 cm long RG58 coaxial cable. The reduction of the FWHM, for all the used cables, is now more pronounced with respect to the measurements using the charge preamplifier. Therefore, the reduction of the signal amplitude with the cable length is comparable in the two cases of MSCA and CA.

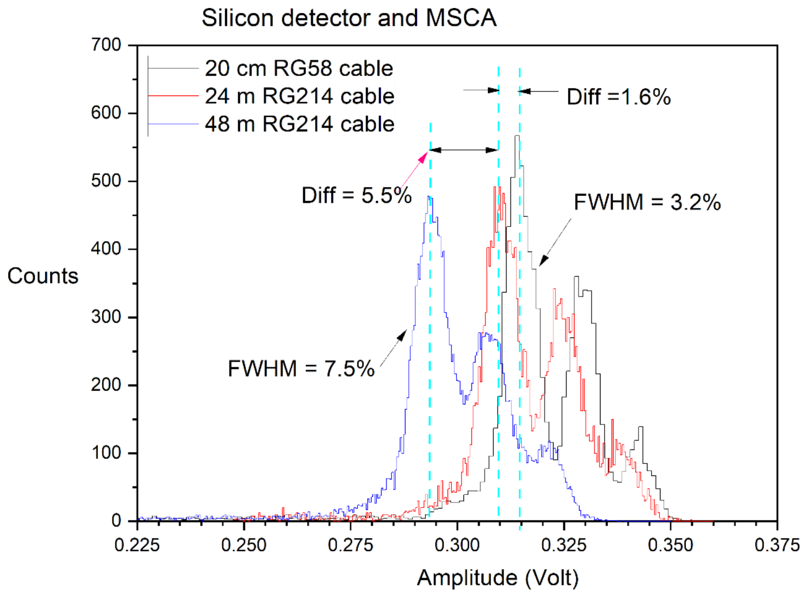

Figure 4. Results with Silicon diode using MSCA amplifier.

2.2 Measurements using Diamond detector

The same set of measurements performed using the Silicon detector and reported above was repeated using the Diamond detector. The results are shown in figure 5 and figure 6 for the case of CA and MSCA, respectively.

Figure 5 shows an interesting result, the sensitive charge preamplifier works well (as expected) with Diamond detector for the case of the 20 cm long RG58 cable, therefore both energy resolution and amplitude are strongly reduced already with 24 m of RG214 double screened cable indicating that this type of coupling is not possible for long detector to front-end electronics distances. Measurements were performed also with 48 m long RG214, but the signal was very poorly resolved and the peak with the lower energy, the one of ^{239}Pu, was almost entirely covered by the noise. Figure 6, in turn, shows how well the MSCA amplifier works with diamond detector. The resolution when connected through the 20 cm RG58 cable is around 2.7%, well comparable with that obtained using CA (see data in figure 5). The effect of the length of RG214 coaxial cable is to reduce of a few percent (respect to 20 cm RG58) both FWHM and peak amplitude, as evidenced by the data reported in figure 6. The latter result is demonstrating the effectiveness of MSCA when connected to diamond detector through long transmission lines. Therefore, we have to remark that this effectiveness is verified only when high quality coaxial cables are used. Test performed with a 5 m long RG58 resulted in a very poor energy resolution PHS spectrum characterized by high level of noise. This fact did not allow the use of MSCA , as already found for the charge sensitive preamplifier and 2 m long RG58.

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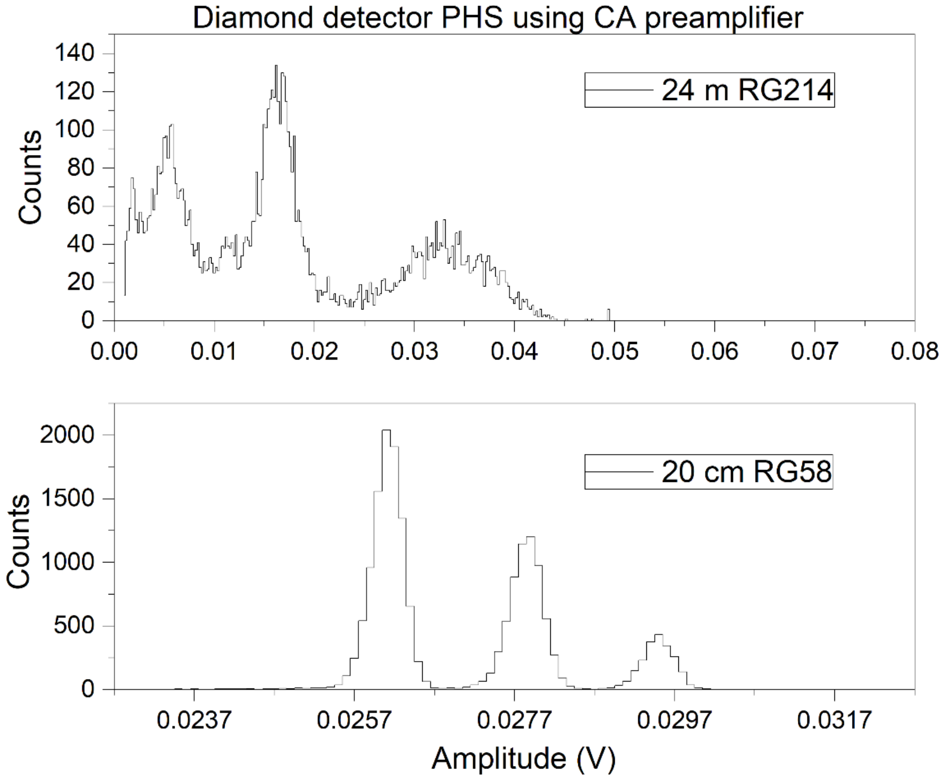

Figure 5. PHS measured using Diamond detector with CA connected through 24 m of RG214 (top) and 20 cm of RG58 (bottom) cables.

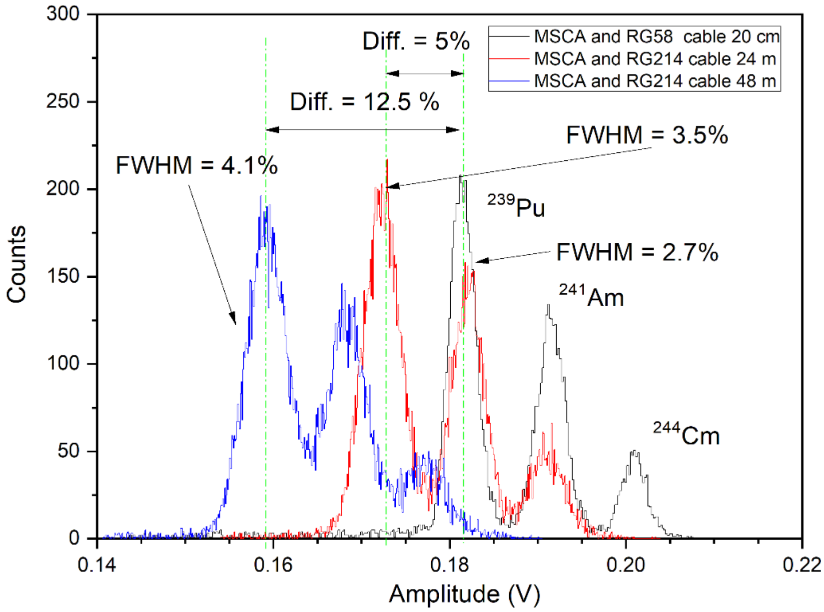

Figure 6. PHS measured using Diamond detector and MSCA. To note the variation in both signal amplitude and FWHM with the different cable length.

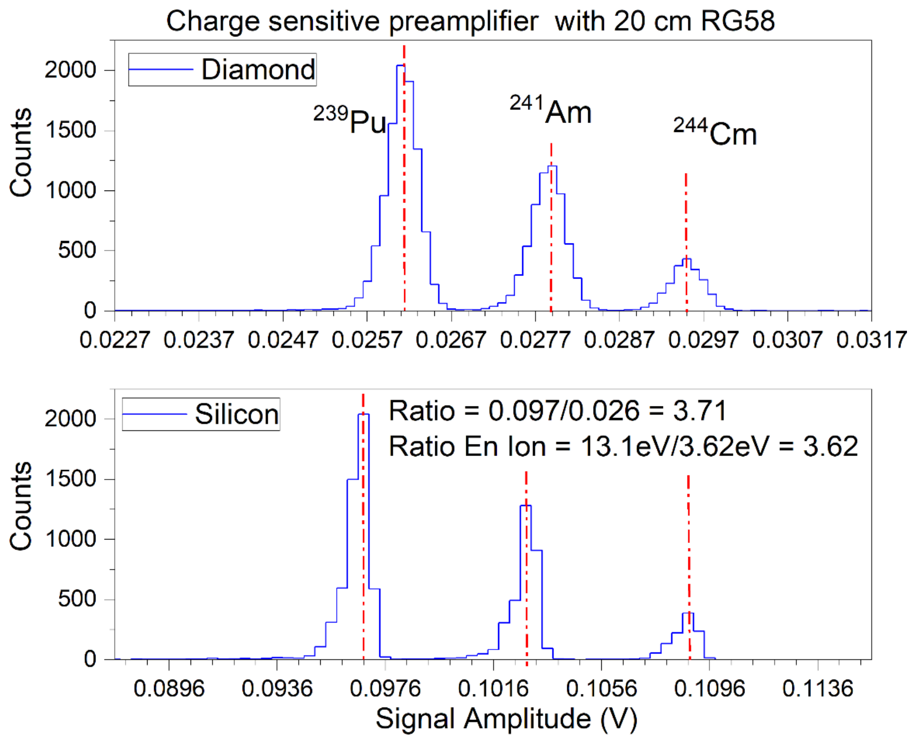

Figure 7. Pulse height spectra for the three peaks alpha source recorded using the Diamond (top) and Silicon (bottom) detectors connected to CA and the RG58 cable, 20 cm long.

3 Results and discussion

A comparison between Silicon and Diamond detectors, when both detectors are connected to the sensitive charge preamplifier by means of 20 cm long RG58 coaxial cable, is reported in figure 7. Figure 7 shows that the PHS measured with Silicon and Diamond detectors have, as expected, a different energy scale. This difference is dictated by the ratio in between the electron-hole pair creation energy that is 13.1 eV for Diamond and 3.62 eV for Silicon [2]. This intrinsic physical property of the two materials reflects in a much smaller signal amplitude for diamond. As shown in figure 7, the expected theoretical ratio between the two electron-hole pair creation energies is $13.1/3.62 = 3.62$ [7] while the measured ratio of the pulses height is 3.71, a difference of about 2.5% error in the energy scale calibration. This result is not surprising since sensitive charge preamplifiers are routinely used to absolutely calibrate Diamond detector efficiency respect to Silicon [7].

It is very interesting to note that the same conclusion is reached when both Silicon and Diamond detectors are connected to MSCA, this is shown in figure 8(a). The relevant data for the various peaks are shown in the figure. Last, but not least, the use of 48 m RG214 does not modify this result (figure 8(b)) demonstrating the effectiveness of MSCA in operating far away from the detectors.

The small difference in the amplitude ratio between the alpha peaks of maximum and minimum energy is due to the claimed non-linearity in the response of commercial MSCA [4] and it is discussed here after.

Insight about the linearity of MSCA can be obtained by looking at the electrical pulses produced by the Diamond and Silicon detectors when connected to this amplifier. The pulses where recoded by the digitizer and, as an example of the results, some pulses are shown in figure 9(a) and 9(b).

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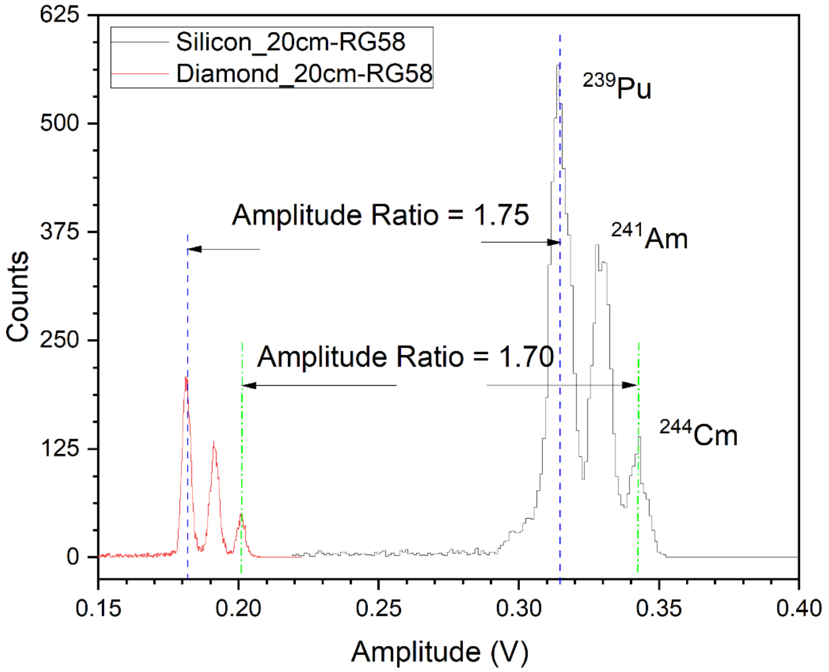
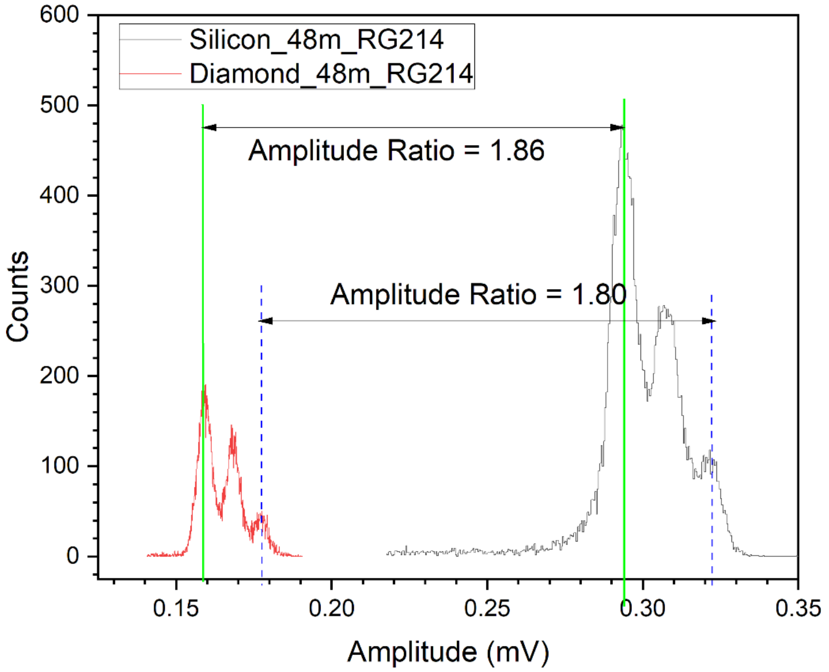


(a)



(b)

Figure 8. Comparison between PHS measured using Diamond and Silicon detectors coupled to MSCA amplifier via different transmission lines; (a) 20 cm RG58; (b) 48 m RG214.

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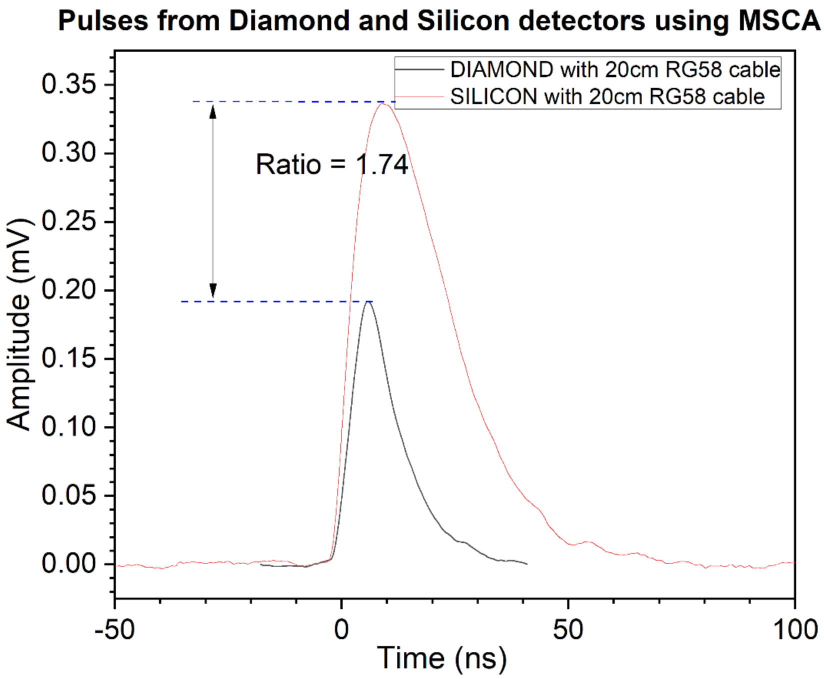
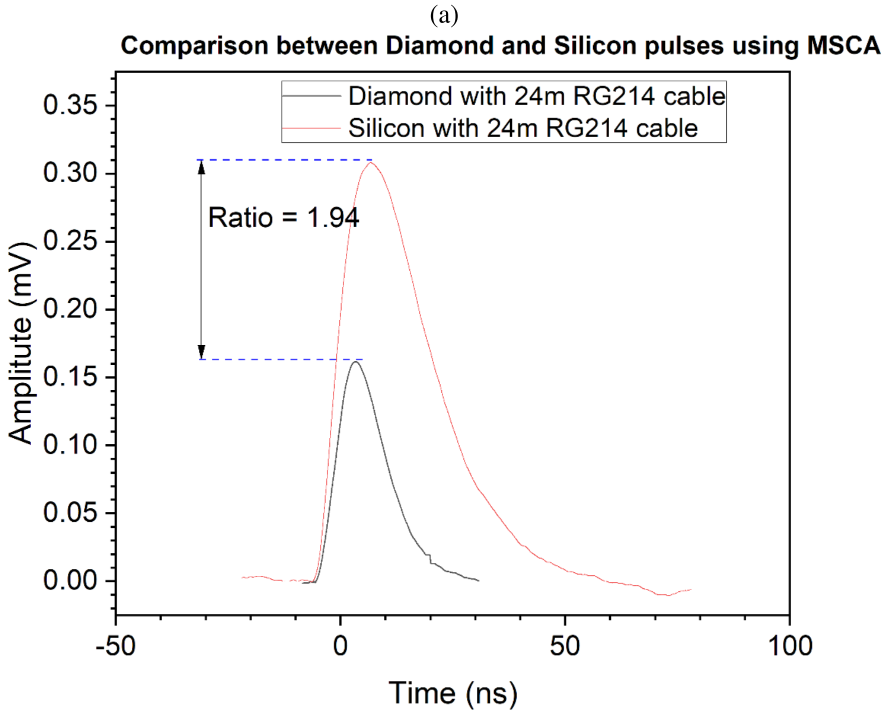


(a)



(b)

Figure 9. (a) Pulses from Diamond and Silicon detectors produced by MSCA when using 20 cm RG58 cable. (b) Pulses from Diamond and Silicon detectors produced by MSCA when using 48 m RG214 transmission line.

Figure 9(b) shows that the introduction of a long transmission line (24 m of RG214 in the case of figure 9(b)) does not introduce distortion in the signal. Therefore, from the ratio between Silicon and Diamond signal amplitudes (Figure 9(b)) it seems that the attenuation of the signal is slight modified.

It is interesting to compare the measured pulses amplitudes, for both Silicon and Diamond detectors, not only between them, but also with the *"expected"* amplitudes calculated using the data of the *amplitude vs. charge plot* reported in figure 1 and 2 of the MSCA data sheet [4]. Table 3 reports the result of this comparison. As it can be seen , the measured signal amplitudes compare quite well with the expected ones both for Silicon and Diamond detectors. The consistency of the data, also for Silicon, seems indicate the capability of MSCA to be coupled also to this type of detector and this could be considered one output of the present work since it was never verified before.

Table 3. Comparison between measured and calculated pulses amplitude. The calculation was performed using the polynomial-regression reported in figure 2 of the commercial MSCA data-sheet [4].

Isotope	**Alfa (MeV)**	**Charge-Silicon (fC)**	**Amplitude-fit_Silicon (mV)**	**Measured-Silicon (mV) from figure 8**
^{239}**Pu**	5,155	2, 28E+02	3, 43E+02	3, 45E+02
^{241}**Am**	5,486	2, 43E+02	3, 43E+02	3, 45E+02
^{244}**Cm**	5,805	2, 57E+02	3, 40E+02	3, 45E+02
Isotope	**Alfa (MeV)**	**Charge Diamond (fC)**	**Amplitude-fit_Diamond (mV)**	**Measured-Diamond (mV) from figure 8**
^{239}**Pu**	5,155	6, 30E+01	1, 61E+02	1, 90E+02
^{241}**Am**	5,486	6, 71E+01	1, 69E+02	1, 90E+02
^{244}**Cm**	5,805	7, 10E+01	1, 77E+02	1, 90E+02
Isotope	**Alfa (MeV)**	**Calculated Si/Dia Amplitude Ratio**	**Measured Si/Dia Amplitude Ratio**	**C/E**
^{239}**Pu**	5,155	2,13	1,75	1,22
^{241}**Am**	5,486	2,03	1,74	1,16
^{244}**Cm**	5,805	1,92	1,70	1,13

4 Conclusions

The commercial MSCA has been tested with both Diamond and Silicon detectors using connection lines of different types and lengths. The scope was to test the claimed capability of MSCA to be located far away from the detector. A three peaks alpha sources was used to irradiate both detectors, PHS were recorded by a digitizer. The PHS measurements were performed in vacuum.

In the present work, for long detector to front-end electronics distances double screened cable RG214, up to 48 m in length, was used, while a 20 cm long RG58 was employed to measure the reference PHS.

The results shown that when coupled to Diamond the MSCA amplifier produces PHS with a worse energy resolution (FWHM) compared to that of a charge sensitive preamplifier. This is observed, already, when using the short (20 cm) RG58 coaxial cable. However, when using RG214

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double screened coaxial cable, MSCA demonstrated to be able to amplify the signals quite well up to the maximum used cable length (48 m). Respect to the reference case of a 20 cm long RG58 coaxial cable, only a small reduction in the signal amplitude (lower than 15%) and in the FWHM was observed. Similar results were obtained also when connecting MSCA to the Silicon detector. This is confirming the claimed capability of MSCA to be located at long distances from the detector, at the cost of accepting a limited worsening in the FWHM as well as in the signal amplitude. This is to be considered if MSCA is to be used for spectrometry. However, no problems were noted in using MSCA just in counting mode.

Last, but not least, the non linearity of the response of MSCA (as claimed and documented in the data-sheet) must be considered when using radiation of energy higher than that employed in the present work. This requires extrapolation of the data presented in this work. Therefore, more care is to be put when considering Silicon detector since the amplitude of its electrical signal is much higher than that of Diamond and thus the non-linearity effect results enhanced.

Acknowledgments

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