

Study of readout and cross-talks for multi-strip RPC with PSpice simulation^{*}

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Abstract An electrical model for multi-strip resistive plate chamber (RPC) is presented, and a comparison between simulation results and test data is carried on. Based on the model, the influences of the RPC's design parameters on the readout are studied with PSpice simulation. Cross-talk (CT) phenomenon is observed and the relative amplitudes of the CT are studied for different design parameters.

Key words RPC, PSpice, readout, CT

PACS 29.40.Cs

1 Introduction

Resistive plate chamber (RPC) was introduced in 1981 by R. Santonico et al.^[1], and recently it has been used in several major experiments performed both with cosmic rays and at accelerators, like ARGONIE, BABAR^[2] at SLAC, Belle^[3] at KEK, PHENIX at RHIC and all major experiments at LHC^[4–8]. Two noticeable advantages of using RPC are the facts that it is far less expensive and it is very flexible for designing external signal readout. In addition, the characteristics of high time resolution and high efficiency are utilized efficiently to measure the time and position of high energy particles which are crossing through the RPC. Multi-layer RPCs have also been employed in several experiments as a fast timing measurement device instead of the traditional scintillator-based time-of-flight detectors. Thus, it's interesting to study the RPC's electrical characteristics to optimize its design, and then enhance its physics performance^[1, 9–17].

The RPC's performance depends on a number of design parameters, such as gas mixture, graphite surface resistivity and geometry of readout strips, etc. In order to study systematically the RPC performance and limit the CT between readout strips, a detailed PSpice^[18] simulation has been developed in this study.

This paper will give a study of RPC's readout and CT with PSpice simulation. We will present an electrical model for multi-strip RPC in section 2, and compare the simulation results with the real data from cosmic rays test. We will show a detailed study on the influences of RPC's design parameters on its readout and CT in section 3, and finally we give a short conclusion in section 4.

2 Electrical model of resistive plate chamber

When the gas layer is crossed by an ionizing particle an electric discharge is suddenly initiated by the liberated electrons, and the detailed working mechanisms of RPC are described in Ref. [15]. The RPCs are working under ~ 10 kV d.c. in order to generate an uniform steady electric field of about 5 kV/mm. There are two different working modes for RPCs adjusted by volts d.c.: the avalanche mode and the streamer mode. The sketch of a single-gap RPC prototype is shown in panel (a) of Fig. 1, (a) and (b) represent the thickness of gas gap and bakelite, respectively.

As shown in panel (b) of Fig. 1, where C_g means the capacitance of active volume of RPC, C_b and R_b represent the capacitance and resistance of active volume of the bakelite, respectively. If ρ is the volume

Received 7 January 2008

^{*} Supported by Ministry of Education of China (306022), and National Natural Science Foundation of China (10635020)

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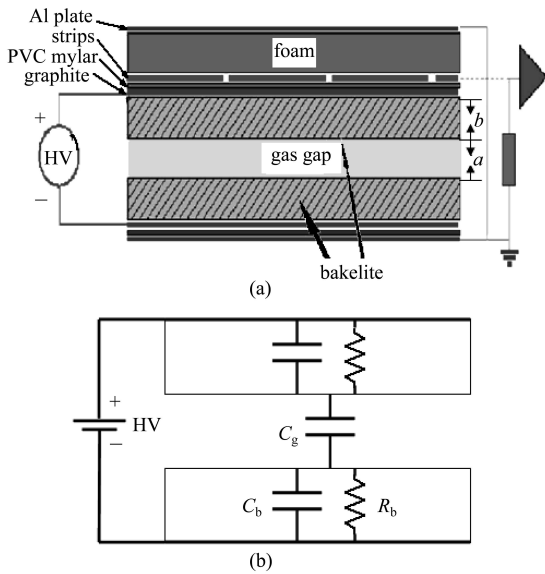


Fig. 1. (a) Sketch of a multi-strip single-gap RPC. (b) Equivalent circuit of RPC corresponding to panel (a), only taking into account the electrical characteristic of gas gap and bakelite.

resistivity of bakelite, ϵ_0 is the dielectric constant, ϵ_r is the relative dielectric constant of bakelite and A is the limited bakelite area interested by a fast current produced by streamer development. Then C_g , C_b and R_b can be calculated^[10] as follows,

$$C_g \approx \epsilon_0 A/a, \quad C_b = \epsilon_r \epsilon_0 A/b, \quad R_b = \rho b/A. \quad (1)$$

The duration of the discharge is typically ~ 10 ns^[15]. Through the above equivalent circuit, we

can calculate the relaxation time τ of the resistive electrode plates according to Eq. (2). It is of the order of $\tau \sim \rho \epsilon_0 \approx 10$ ms.

$$\tau = \rho \epsilon_0 (1 + b/(2\epsilon_r \cdot a)). \quad (2)$$

An electrical model for multi-strip RPC is presented, and its schematic layout per one strip is shown in Fig. 2.

In Fig. 2, the points indicated by Marker V and I are the readout signal (voltage) and the fast streamer current, respectively. R_0 is the strip load, R_s is the surface resistance of bakelite, and R_c is the graphite surface resistance. C_p is the coupling capacitance of “strip-to-strip”, C_{rs} and C_s are the distributed capacitances of “strip-to-graphite” and “strip-to-ground”, respectively. C_p and C_s can be calculated^[19, 20] with the following Eq. (3) and (4).

$$C_p (\text{pF/cm}) = 0.12 \frac{t}{w} + 0.09(1+k) \lg \left(1 + \frac{2w}{s} + \frac{w^2}{s^2} \right), \quad (3)$$

$$C_s = \epsilon_r^* \epsilon_0 \frac{L \cdot w}{d}, \quad (4)$$

where t is the strip thickness, w is the strip width, L is the strip length, s is the strip separation, and k is the relative dielectric constant of the backing material between the bakelite and strips; ϵ_r^* is the relative dielectric constant of foam between the strip and the ground plane, and d is its thickness. C_{rs} can be estimated with the same method of C_s , and is determined by the width of strip and thickness h of the backing material. In simulation, a positive triangular pulse

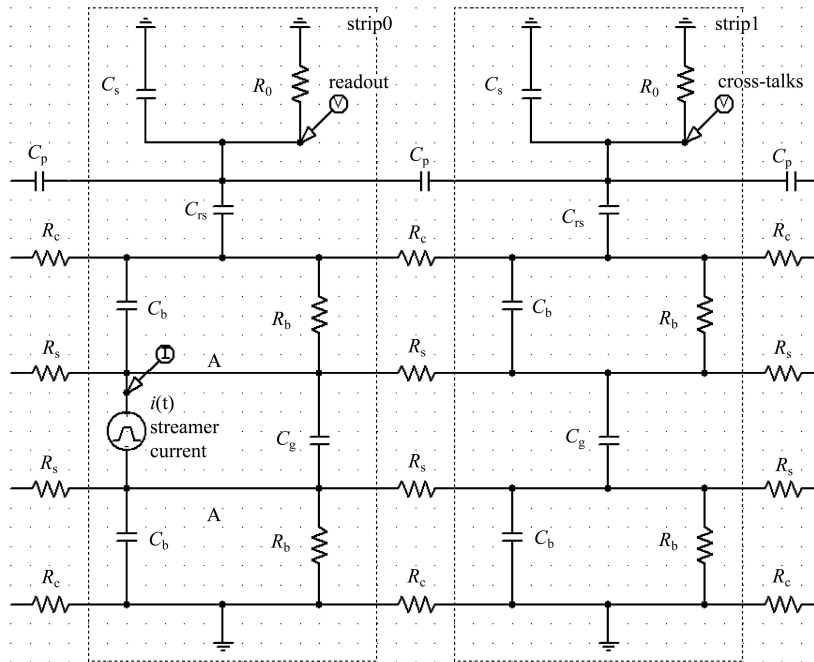


Fig. 2. Schematic layout of electrical model of two neighboring strips for multi-strip RPC.

is set as the fast streamer current, its total charge is ~ 100 pC, the rise-time is 3 ns and the duration time is 10 ns (FWHM)^[15]. Assuming the discharge point is centered in the middle of the reference strip. Then we ignore the direct induction of the streamer current on the side strips, because it's negligible for 6.3 cm wide strips according to the study in Ref. [13]. During the streamer current duration, firstly the current charges up the C_b and C_{rs} flowing through the reference strip load R_0 , but at the same time any lateral C_{rs} (side strips') also receives an extra charge from the reference's one through R_c .

We set the strip ($i=0$) as the reference strip whose readout is picked up as the readout signal, and strip ($i=1, 2$) represent side strips whose readout are taken as the CT. We define the relative CT amplitude^[13] r_{i0} as

$$r_{i0} = A_i/A_0, \quad (5)$$

where A_i , A_0 are the amplitudes of signals on strip “ i ” and the reference strip ($i=0$), respectively. For bipolar signals, we only consider the pulses of reference signal polarity. For our RPC prototype there are four readout strips ($i=0, \pm 1, 2$), here we will consider the CT on strip ($i=-1$) in the relative CT amplitude study subsection.

We follow typical single-gap RPC design for our four-strip RPC prototype: Italian bakelite of $\rho \approx 10^{10}$ $\Omega\cdot\text{cm}$ and its surface resistivity 4 G Ω /square, gas-gap and bakelite with thickness of 2.0 mm, gas mixture, graphite surface resistivity of 200 k Ω /square and lemo cable is directly soldered to the copper strip with characteristic resistance of 50 Ω . The readout strips are constructed by typing the copper strips on 1 mm thick G10 sheet, and they are 63 mm wide and 460 mm long with 2 mm gaps between them. During the cosmic rays test, the RPC prototype was operated under 9500 V d.c. Here $\epsilon_r=4.5$ and $k=3.5$. To the prototype, we get the PSpice simulation result as shown in the upper panel of Fig. 3. And the result of cosmic rays test is shown as the lower panel of Fig. 3, we only took signals in the case that the streamer process centered in the middle of the strip ($i=0$). The typical waveforms of signals are shown for the reference strip $i=0$ and for strips $i=1$ and 2, and the trigger signal is generated by scintillator detectors. These signals were observed with a digital oscilloscope in the test.

As shown in Fig. 3 (upper), the signals' shape and their duration time show a good agreement between the simulation result and the test data. For the strip ($i=0$), the readout looks like an exponentially negative tail. This can be explained by the discharge of C_b and C_{rs} through R_c . For the strip ($i=1$), the CT

signal has a bipolar shape with the leading pulse of the reference signal polarity and looks like a derivative of the reference negative signal on strip ($i=0$). This differentiation is caused by C_p (coupling capacitance of “strip-to-strip”). For strip ($i=2$) the CT signals are also bipolar. It is clear that the discharge time (electrode shielding time) of R_c - C_{rs} - C_b network is much longer than the streamer current duration, as expected the pulses are undistorted transmitted through R_c . This effect was predicted in Ref. [17]. In simulation, $r_{10}=0.252$ and $r_{20}=0.044$. For our test data, the r_{10} and r_{20} are 0.237 and 0.043 in average, respectively. We see that the relative CT amplitudes match well too. Based on the electrical model, we have done simulations to study the RPC's readout and CT in detail.

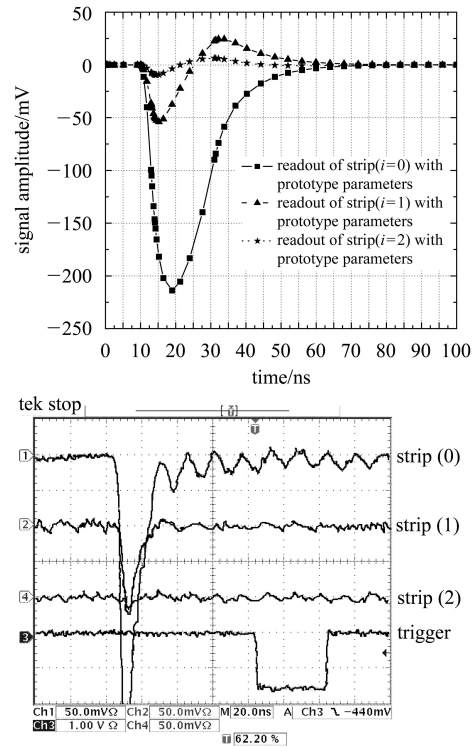


Fig. 3. (upper) Signal from reference strip ($i=0$) and CT from side strip ($i=1, 2$) with PSpice simulation. (lower) Signal waveforms from cosmic rays test.

3 Results of PSpice simulation

3.1 Readout and CT vs. RPC's design parameters

The waveforms of RPC's signals are shown in Fig. 4(a–f), and all of them are observed in Probe workspace of PSpice. Fig. 4(a–f) describe the readout and CT of RPC under different values of C_g , C_b , R_b , C_{rs} , C_p , C_s , respectively.

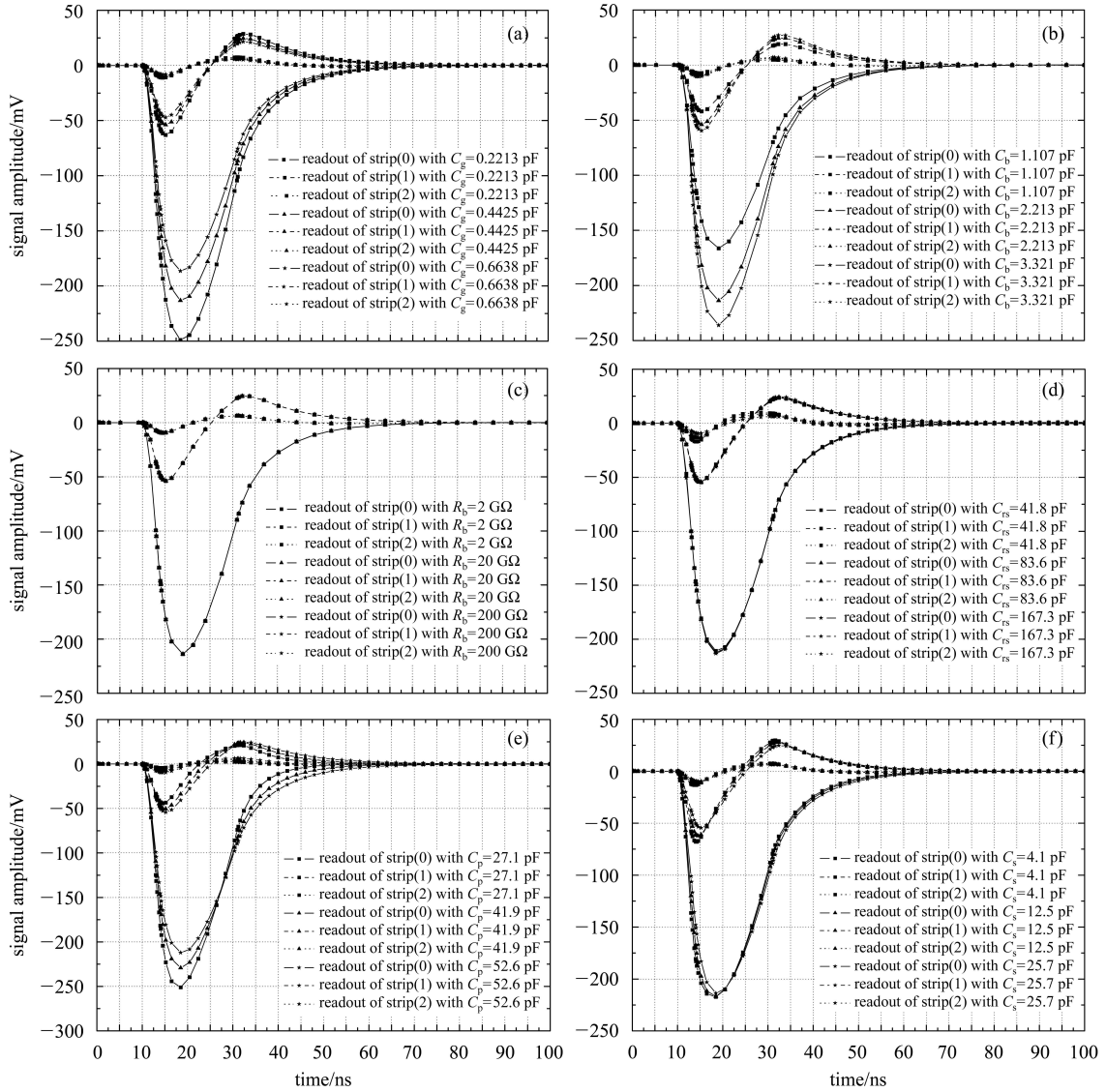


Fig. 4. The waveforms of readout and CT: signals vs. C_g (a), signals vs. C_b (b), signals vs. R_b (c), signals vs. C_{rs} (d), signals vs. C_p (e), signals vs. C_s (f).

Signals in Fig. 4 are obtained with R_c of 200 k Ω /square. It's observed that all readout signals don't have long tails and the CT have bipolar shapes. This characteristics agree with the experimental data in Ref. [13]. For the bipolar signals, the pulse amplitudes of reference signal polarity are larger than the opposite ones. For Fig. 4(a), the amplitudes of both the readout signal and CT are decreasing while C_g is increasing. For Fig. 4(b, c), the amplitudes of both the readout signal and CT increase as C_b increases, but are not sensitive to R_b 's changes. For Fig. 4(d), as C_{rs} increases the reference amplitude from strip ($i=0$) increases unobviously, but the CT amplitudes of strips ($i=1, 2$) decrease much noticeable with respected to the reference amplitude. For Fig. 4(e), the readout signal decreases and the CT increase obviously as C_p increases. For Fig. 4(f), both the readout

signal and the CT's amplitudes decrease unnoticeably as C_s increases. In addition, we found that the pulse amplitudes of readout and CT are sensitive to the changes of C_g and C_b , but their relative CT amplitudes are approximately not changed, as seen in Table 1.

Table 1. Relative CT amplitudes of C_g and C_b .

C_g /pF	r_{10}	r_{20}	C_b /pF	r_{10}	r_{20}
0.2213	0.252	0.044	1.107	0.25	0.044
0.4425	0.252	0.044	2.213	0.252	0.044
0.6638	0.251	0.044	3.321	0.251	0.044

As we know, the electrode shielding time is related to R_c and C_{rs} . In order to find out the relations between R_c and C_{rs} , we did a simulation and observed an interesting phenomenon shown in Fig. 5.

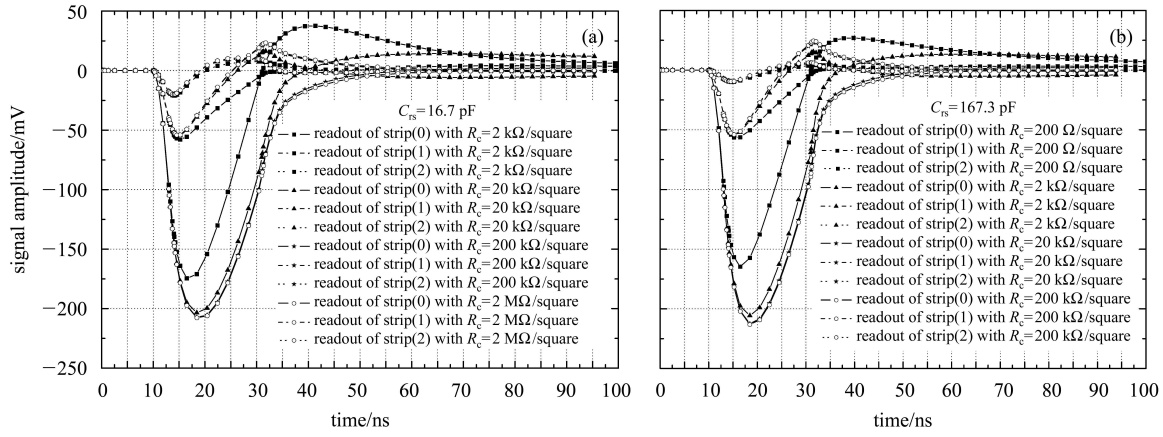


Fig. 5. Readout signal from the reference strip and CT from the side strips with different R_c under $C_{rs} = 16.7$ pF (a) and $C_{rs} = 167.3$ pF (b).

As shown in Fig. 5, for the lower graphite resistivity we see a long tail for the readout signal together with an obvious decrease in the peak amplitude, and the derivation effect in the reference strip is larger. Meanwhile long pulses appear on the side strips ($i=1, 2$), and these long pulses have the polarity of the reference signal, together with a little increase in peak amplitude. In Fig. 5(a), when R_c is reducing to 2 k Ω /square or 20 k Ω /square, the electrode shielding time of the graphite becomes comparable to the streamer current duration, so the pulses of both reference and side strips show a differentiation effect. This effect appears too in Fig. 5(b) when R_c is going to 200 Ω /square or 2 k Ω /square. This effect was mentioned in Refs. [13, 17].

In addition, we see that amplitudes of the reference signal increase firstly as R_c increases, but it no longer increases visibly when the R_c reaches up to a

“critical value”. For Fig. 5(a), the “strip-to-graphite” dielectric gap is the 1 cm thick G10 sheet corresponding to C_{rs} value of 16.7 pF, and the “critical value” of R_c is about 200 k Ω /square. In Fig. 5(b), we replace the 1 cm thick G10 sheet with 1 mm G10 sheet corresponding to the C_{rs} value of 167.3 pF, then the “critical value” of R_c is shifted to about 20 k Ω /square lower by a factor of 10. Such characteristics called “transparency” have been studied in Ref. [17].

3.2 Relative CT amplitude study

Based on the results as above, we know that the amplitudes of readout signal and CT can be influenced by C_g and C_b , and these two parameters are determined by the gas-mixture properties and the volume resistivity of bakelite, respectively. The other noticeable characteristics are that both the readout signal and the CT are sensitive to the RPC’s design

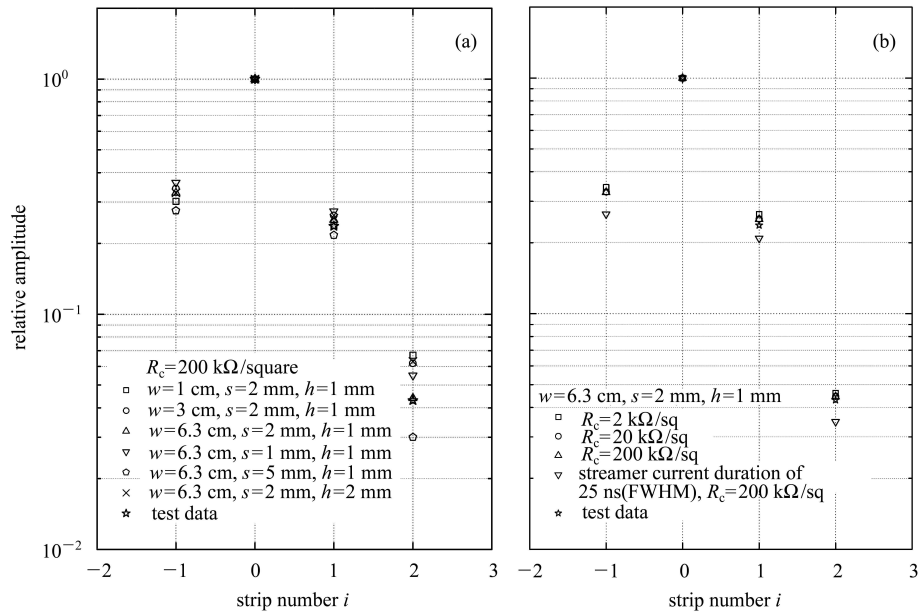


Fig. 6. Distribution of relative CT amplitudes over strips for different geometry parameters (a) and for different graphite surface resistivity and long streamer current duration (b), test data.

parameters: w , s , h and R_c . The relative CT amplitudes r_{i0} with different parameters for each strip ($i = \pm 1, 2$) are shown in Fig. 6, and the test data are included.

In Fig. 6, the distribution with star marker indicates our cosmic rays test data, and the distribution with triangle marker means the simulation result with our RPC prototype parameters. It shows that they are agreeable. One thing I must mention is that we didn't take into account the direct induction of the streamer on the neighboring strips too when w was set to 1 cm or 3 cm. In the upper panel of Fig. 6, the CT increased when the strip width w decreased or the strip separation s decreased. Also we found that the CT increased when the G10 sheet thickness h increased, and this effect can be explained with Fig. 4(d). In Fig. 6(b), we found the relative CT amplitudes are influenced unnoticeably by graphite surface resistivity R_c . We did a simulation which the streamer current duration was shifted to 25 ns (FWHM), then we observed the amplitude of reference signal was much larger than the one with 10 ns duration, but the amplitudes from side strips increased just a little with respected to the increase of reference readout. Therefore, we see the distribution of the relative CT amplitude becomes narrower as shown in the lower panel of Fig. 6.

4 Conclusion

According to the PSpice simulation results pre-

sented above, we find the multi-strip RPC's readout and CT are dependent on its design parameters.

1) For the test data, the amplitude of readout signal is about 201 mV, which was calculated with statistical method. So, the amplitudes of the readout signal from both the simulation and the real data are equally matched. Together with good matches in waveforms and relative CT amplitudes, the simulation results show a good agreement with the real data, and also are consistent with the studies in Refs. [13, 17]. All of these suggest that the electrical model for RPC we presented in this paper is reasonable.

2) The pulse amplitudes of the readout signal and CT are sensitive to C_g , C_b , C_p and R_c . But for the changes of C_g and C_b , their relative CT amplitudes are nearly not changed. So the CT are dependent on C_p with respected to C_g , C_b and C_s . In the development of RPC, we should try to make C_p small, then we can get an increase in the peak amplitude of reference strip while getting a loss in CT.

3) Our results about the HV electrode "transparency" are in accordance with those in Ref. [17]. The distributions of relative CT amplitude for low and high graphite surface resistivity are also in conformity with those in Ref. [13].

Yaping Wang would like to thank the financial support from Xiao-chun He and helps from his lab at Gerogia State University, Atlanta, U. S., during his visit to the lab.

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