Spinor Field Realizations of Non-critical $W_{2,s}$ Strings *

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Abstract

In this paper, we construct the nilpotent Becchi-Rouet-Stora-Tyutin (BRST) charges of spinor non-critical $W_{2,s}$ strings. The cases of $s = 3, 4$ are discussed in detail, and spinor realization for $s = 4$ is given explicitly. The BRST charges are graded.

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1. Introduction

As is well known, $W$ algebra has found remarkable applications in $W$ gravity and $W$ string theories since its discovery in 1980’s [1,2]. Furthermore, it appears in the quantum Hall effect, black holes, in lattice models of statistical mechanics at criticality, and in other physical models [3,4] and so on.

The $BRST$ formalism [5] has turned out to be rather fruitful in the study of string theories and the study of critical and non-critical $W$ string theories. The $BRST$ charge for $W_3$ string was first constructed in [6], and the detailed studies of it can be found in [6-12]. A natural generalization of the $W_3$ string, i.e. the critical $W_{2,s}$ string, is a higher-spin string with local spin-2 and spin-$s$ symmetries on the world-sheet. Critical $BRST$ charges for such theories have been constructed for $s = 4, 5, 6, 7$ [13-15]. For a system with non-linear symmetry, however, the critical and non-critical $BRST$ charges are intrinsically different. In [16,17], a $BRST$ charge for the so-called non-critical $W_3$ string was found. Such $W_3$ string is a theory of $W_3$ matter coupled to $W_3$ gravity; it is a generalization of two-dimensional matter coupled to gravity. Shortly, a non-critical $BRST$ charge for the $W_{2,4}$ string was constructed by generalizing the $W_3$ results of [16-18]. And some of the physical states, including some of the ghost-number zero ground-ring generators, were obtained.

However, all of these theories about $W_{2,s}$ strings mentioned above are based on scalar field. In the work [19], we pointed out the reason that the scalar $BRST$ charge is difficult to be generalized to a general $W_N$ string. At the same time, we found the methods to construct the spinor field realization of critical $W_{2,s}$ strings and $W_N$ strings. Assuming the $BRST$ charges of the $W_{2,s}$ strings and $W_N$ strings are graded, we studied the exact spinor field realizations of $W_{2,s}(s = 3, 4, 5, 6)$ strings and $W_N(N = 4, 5, 6)$ strings [19-22] by using our program.

Since so far there is no work focussed on the research of spinor non-critical $W_{2,s}$ strings, we will construct the nilpotent $BRST$ charges of spinor non-critical $W_{2,s}$ strings by taking into account the property of spinor field in this paper. To construct a $BRST$ charge one must first solve the forms of $T_M$ and $W_M$ determined by the OPEs of $TT$, $TW$ and $WW$. Then direct substitution of these results into $BRST$ charge leads to the grading realizations. Such constructions are discussed for $s = 3, 4$. These results will be of importance for constructing super $W$ strings, and they provide the essential ingredients.

This paper is organized as follows. We begin in Sec. 2 by reviewing spinor field realizations of critical $W_{2,s}$ strings which were obtained in [19-22]. Then we give the grading $BRST$ method to construct spinor field $BRST$ charges of non-critical $W_{2,s}$ strings. Subsequently, we mainly discuss the spinor field realizations of the non-critical $W_{2,3}$ string and $W_{2,4}$ string, and construct a non-critical $BRST$ charge for the $W_{2,4}$ string. And finally, a brief conclusion is given.
2. Review of spinor field realizations of critical $W_{2,s}$ strings

In [20] the spinor BRST charges were constructed for critical $W_{2,s}$ strings theories, that is, for pure $W_{2,s}$-matters. The authors introduce the $(b, c)$ ghost system for the spin-2 current, and the $(\beta, \gamma)$ for the spin-$s$ current, where $b$ has spin 2 and $c$ has spin -1 whilst $\beta$ has spin $s$ and $\gamma$ has spin $(1-s)$. The ghost fields $b, c, \beta, \gamma$ are all bosonic and communicating. They satisfy the OPEs

$$b(z)c(\omega) \sim \frac{1}{z-\omega}, \quad \beta(z)\gamma(\omega) \sim \frac{1}{z-\omega},$$

in the other case the OPEs vanish. The spinor field $\psi$ has spin 1/2 and satisfies the OPE

$$\psi(z)\psi(\omega) \sim -\frac{1}{z-\omega}.$$  

Then the BRST charge for the spin-2 plus spin-$s$ string takes the form:

$$Q_B = Q_0 + Q_1,$$  

$$Q_0 = \oint dz \left[ c(T^{eff} + T_\psi + KT_{bc} + yT_{\beta\gamma}) \right],$$  

$$Q_1 = \oint dz \gamma F(\psi, \beta, \gamma),$$  

where $K, y$ are pending constants and the operator $F(\psi, \beta, \gamma)$ has spin $s$ and ghost number zero. The energy-momentum tensors in (4) are given by

$$T_\psi = -\frac{1}{2} \partial^2 \psi,$$  

$$T_{\beta\gamma} = s\beta \partial \gamma + (s-1)\partial\beta \gamma,$$  

$$T_{bc} = 2b\partial c + \partial bc,$$  

$$T^{eff} = -\frac{1}{2} \eta_{\mu\nu} \partial Y^\mu Y^\nu.$$  

The BRST charge is graded with $Q_0^2 = Q_1^2 = \{Q_0, Q_1\} = 0$. The first condition $Q_0^2 = 0$ is satisfied for an arbitrary $s$. The remaining two nilpotency conditions determine the precise form of the operator $F(\psi, \beta, \gamma)$ and the exact $y$. They have no constraint for the coefficient $K$. The particular method used to construct $F(\psi, \beta, \gamma)$ can be found in [20,22]. We have obtained the solutions for $s = 3, 4, 5, 6$ and discussed the case of any $s$ [19-22].

3. Spinor field realizations of non-critical $W_{2,s}$ strings

The non-critical $W_{2,s}$ strings are the theories of $W_{2,s}$ gravity coupled to a matter system on
which the $W_{2,s}$ algebras are realized. Now we give the spinor field realizations of them.

The $BRST$ charge takes the form:

$$Q_B = Q_0 + Q_1,$$

$$Q_0 = \oint dz \, c(T^{eff} + T_\psi + T_M + KT_{bc} + yT_{\beta\gamma}),$$

$$Q_1 = \oint dz \, \gamma F(\psi, \beta, \gamma, T_M, W_M),$$

where the matter currents $T_M$ and $W_M$, which have spin 2 and $s$ respectively, generate the $W_{2,s}$ algebra, whilst the energy-momentum tensors $T_\psi, T_{\beta\gamma}, T_{bc}$ and $T^{eff}$ are given by (6-9). The $BRST$ charge generalizes the one for the scalar non-critical $W_{2,s}$ strings, and it is also graded with $Q_2^0 = Q_2^1 = \{Q_0, Q_1\} = 0$. Again the first condition is satisfied for any $s$, and the remaining two conditions determine the coefficients of the terms in $F(\psi, \beta, \gamma, T_M, W_M)$ and $y$.

In order to build the spinor non-critical $W_{2,s}$ strings theories, we need the explicit realizations for the matter currents $T_M$ and $W_M$. Generally, the two-spinor realizations of the $W_{2,s}$ algebras take the form:

$$T_M = T_{Y_1} + T_{Y_2} = -\frac{1}{2} \partial Y_1 Y_1 - \frac{1}{2} \partial Y_2 Y_2,$$

$$W_M = W_{Y_1} + W_{Y_1} + W_{Y_1, Y_2},$$

where $W_{Y_i}(i = 1, 2)$ indicates the terms which are formed by $Y_i$, and $W_{Y_1, Y_2}$ corresponds to that of $Y_1$ and $Y_2$. In conformal OPE language the $W_{2,s}$ algebra takes the following forms:

$$T(z)T(\omega) \sim \frac{C/2}{(z - \omega)^2} + \frac{2T(\omega)}{(z - \omega)^2} + \frac{\partial T(\omega)}{(z - \omega)},$$

$$T(z)W(\omega) \sim \frac{sW(\omega)}{(z - \omega)^2} + \frac{\partial W(\omega)}{(z - \omega)},$$

$$W(z)W(\omega) \sim \frac{C/s}{(z - \omega)^2s} + \sum_\alpha \frac{P_\alpha(\omega)}{(z - \omega)^{\alpha+1}},$$

in which $P_\alpha(\omega)$ are polynomials in the primary fields $W, T$ and their derivatives. For an exact $s$, the precise form of $W$ and the corresponding central charge $C$ can be solved by means of these OPEs. Substituting them into (12), we can get the final result of $Q_1$. So, the $BRST$ charge $Q_B$ for the spinor non-critical $W_{2,s}$ string can be obtained.

4. The particular results

In present section, using the grading $BRST$ method and the procedure mentioned in Sec. 3, we will discuss the exact solutions of spinor field realizations of the non-critical $W_{2,s}$ strings for the cases of $s=3$ and 4.
4.1. Spinor field realization of the non-critical $W_{2,3}$ string

In this case, $Q_B$ takes the form of (10). The most extensive combinations of $F$ in (12) with correct spin and ghost number can be constructed as following:

$$F(\psi, \beta, \gamma, T_M, W_M) = f_3[1] \beta^3 \gamma^3 + f_3[2] \beta \beta \gamma^2 + f_3[3] \beta \beta \gamma + f_3[4] \beta \gamma \partial \psi \psi + f_3[5] \beta \partial \gamma$$

$$+ f_3[6] \partial^2 \psi \psi + f_3[7] \beta \gamma T_M + f_3[8] \partial \psi \psi T_M + f_3[9] \partial T_M + f_3[10] W_M.$$  \hfill (15)

Substituting (15) back into (12) and imposing the nilpotency conditions, we can determine $y$ and $f_3[i] (i = 1, 2, \ldots, 10)$. They correspond to three sets of solutions, respectively. i.e.

(i) $y = 0$ and

$$f_3[4] = f_3[6] = f_3[7] = f_3[8] = f_3[9] = f_3[10] = 0,$$

and $f_3[1], f_3[2], f_3[3], f_3[5]$ are arbitrary constants but do not vanish at the same time.

(ii) $y = 1$ and

$$f_3[1] = \frac{1}{150} (-7f_3[3] + 3f_3[5]), \quad f_3[2] = \frac{1}{15} (7f_3[3] - 3f_3[5]),$$

$$f_3[4] = \frac{22}{5} f_3[3] - \frac{78}{5} f_3[5], \quad f_3[6] = -11f_3[3] + 39f_3[5] - \frac{5}{2} Cmf_3[7],$$

$$f_3[8] = 0, \quad f_3[9] = -\frac{5}{2} f_3[7],$$

where $f_3[3], f_3[5], f_3[7]$ and $f_3[10]$ are arbitrary constants but do not vanish at the same time. $Cm$ is the matter central charge corresponding to the matter currents $T_M$ and $W_M$.

(iii) $y$ is an arbitrary constant and

$$f_3[4] = f_3[6] = f_3[7] = f_3[8] = f_3[9] = f_3[10] = 0,$$

$$f_3[1] = -\frac{8}{39} f_3[5], \quad f_3[2] = \frac{16}{11} f_3[5], \quad f_3[3] = \frac{39}{11} f_3[5],$$

where $f_3[5]$ is an arbitrary constant but does not vanish.

Now we turn to the construction of the form of $W$. The OPE $W(z)W(\omega)$ in (14) is given by [1]

$$W(z)W(\omega) \sim \frac{C/3}{(z - \omega)^6} + \frac{2T}{(z - \omega)^4} + \frac{\partial T}{(z - \omega)^3}$$

$$+ \frac{1}{(z - \omega)^2} (2\Theta \Lambda + \frac{3}{10} \partial^2 T) + \frac{1}{(z - \omega)} (\Theta \partial \Lambda + \frac{1}{15} \partial^3 T),$$  \hfill (16)

where

$$\Theta = \frac{16}{22 + 5C}, \quad \Lambda = T^2 - \frac{3}{10} \partial^2 T.$$  \hfill (17)

We can write down the most general possible structure of $W_M$ for $s = 3$:

$$W_M = g_3[1] \partial^2 Y_1 Y_1 + g_3[2] \partial^2 Y_2 Y_2 + g_3[3] \partial^2 Y_1 Y_2 + g_3[4] Y_1 \partial^2 Y_2 + g_3[5] \partial Y_1 \partial Y_2.$$  \hfill (18)
Unfortunately, we find there is no nontrivial solution for the two-spinor realization of $W_{2,3}$ algebra.

4.2. Spinor field realization of the non-critical $W_{2,4}$ string

Similarly, for the case $s = 4$, $Q_B$ also takes the form of (10) and $F$ can be expressed in the following form:

$$F(\psi, \beta, \gamma, T_M, W_M) = f_4[1] \beta^4 \gamma^4 + f_4[2] (\partial \beta)^2 \gamma^2 + f_4[3] \beta^3 \gamma^2 \partial \gamma + f_4[4] \beta^2 (\partial \gamma)^2$$

$$+ f_4[5] \beta^2 \gamma^2 \partial \psi \psi + f_4[6] \partial \beta \gamma \partial \psi \psi + f_4[7] \beta \partial \gamma \partial \psi \psi + f_4[8] \beta^2 \gamma^2$$

$$+ f_4[9] \partial \beta \partial \gamma + f_4[10] \partial \beta \partial \gamma^2 + f_4[11] \partial^2 \psi \partial \psi + f_4[12] \beta \partial^3 \gamma$$

$$+ f_4[13] \partial^3 \psi \psi + f_4[14] \partial \beta \gamma T_M + f_4[15] \beta \partial \gamma T_M + f_4[16] \partial \psi \psi T_M$$

$$+ f_4[17] \beta \gamma \partial T_M + f_4[18] T_M^2 + f_4[19] \partial^2 T_M + f_4[20] W_M.$$ (19)

There are three sets of solutions:

(i) $y = 0$ and

$$f_4[5] = f_4[6] = f_4[7] = f_4[11] = f_4[13] = f_4[16] = f_4[18] = f_4[19] = f_4[20] = 0,$$

$$f_4[14] = f_4[17] = \frac{1}{2} f_4[15],$$

where $f_4[1], f_4[2], f_4[3], f_4[4], f_4[8], f_4[9], f_4[10], f_4[12], f_4[15]$ are arbitrary constants but do not vanish at the same time.

(ii) $y = 1$ and

$$f_4[1] = \frac{1}{468930} (58 f_4[6] + 3(38 f_4[7] + 21(289 f_4[8] + 5 C m(-2 f_4[14] + f_4[15])))),$$

$$f_4[2] = \frac{1}{15312} (116 f_4[6] + 63 f_4[7] + 6(2571 f_4[8] + 50 C m(-2 f_4[14] + f_4[15]))),$$

$$f_4[3] = \frac{1}{20097} (58 f_4[6] + 3(38 f_4[7] + 21(289 f_4[8] + 5 C m(-2 f_4[14] + f_4[15]))),$$

$$f_4[4] = \frac{1}{232} (5 f_4[7] + 2(57 f_4[8] + 5 C m(-2 f_4[14] + f_4[15]))),$$

$$f_4[5] = \frac{1}{21} (-4 f_4[6] + 3 f_4[7]),$$

$$f_4[9] = \frac{1}{696} (7 f_4[7] + 1134 f_4[8] + 232 f_4[10] - 28 C m f_4[14] + 14 C m f_4[15]),$$

$$f_4[11] = \frac{1}{70} (330 f_4[6] + 10 f_4[7] + 3 C m(278 f_4[14] - 139 f_4[15] + (22 + 5 C m) f_4[18])),$$

$$f_4[12] = \frac{1}{1392} (-35 f_4[7] + 2(-399 f_4[8] + 464 f_4[10] + 70 C m f_4[14] - 35 C m f_4[15])),$$

$$f_4[13] = \frac{1}{210} (-110 f_4[6] + 160 f_4[7] - C m(278 f_4[14] - 139 f_4[15] + (22 + 5 C m) f_4[18])),$$

$$f_4[16] = \frac{2}{5} (278 f_4[14] - 139 f_4[15] + (22 + 5 C m) f_4[18]),$$

$$f_4[17] = \frac{1}{2} f_4[15],$$

$$f_4[18] = \frac{1}{3} f_4[15],$$

$$f_4[19] = \frac{1}{5} f_4[15].$$
\[ f_{4[17]} = -2f_{4[14]} + \frac{3}{2}f_{4[15]}, \]
\[ f_{4[19]} = \frac{1}{10}(28f_{4[14]} - 14f_{4[15]} - 3f_{4[18]}), \]
where \( f_{4[6]}, f_{4[7]}, f_{4[8]}, f_{4[10]}, f_{4[14]}, f_{4[15]}, f_{4[18]}, f_{4[20]} \) are arbitrary constants but do not vanish at the same time.

(iii) \( y \) is an arbitrary constant and

\[ f_{4[5]} = f_{4[6]} = f_{4[7]} = f_{4[11]} = f_{4[13]} = f_{4[16]} = f_{4[18]} = f_{4[19]} = f_{4[20]} = 0, \]
\[ f_{4[1]} = \frac{867}{23300}f_{4[8]}, \quad f_{4[2]} = \frac{2571}{2552}f_{4[8]}, \quad f_{4[3]} = \frac{289}{319}f_{4[8]}, \quad f_{4[4]} = \frac{57}{116}f_{4[8]}, \]
\[ f_{4[9]} = \frac{189}{116}f_{4[8]} + \frac{1}{3}f_{4[10]}, \quad f_{4[12]} = -\frac{133}{232}f_{4[8]} + \frac{2}{3}f_{4[10]}, \]
\[ f_{4[14]} = f_{4[17]} = \frac{1}{2}f_{4[15]}, \]
where \( f_{4[8]}, f_{4[10]}, f_{4[15]} \) are arbitrary constants but do not vanish at the same time.

Note that the coefficient \( f_{4[20]} \) for the term of \( W_M \) in \( F(\psi, \beta, \gamma, T_M, W_M) \) is zero for the first and last solutions, we only need the result with \( y = 1 \) for non-critical \( W^2 \) string.

Let us now consider the construction of \( W \) with \( s = 4 \). The OPE \( W(z)W(\omega) \) for \( W_{2,4} \) algebra is given by [23,24]:

\[
W(z)W(\omega) \sim \left\{ \frac{2T}{(z-w)^6} + \frac{\partial T}{(z-\omega)^5} + \frac{3\partial^2 T}{10(z-\omega)^4} \right. \\
\left. + \frac{1}{15}(z-\omega)^3 \right\} + \left\{ \frac{1}{84}(z-\omega)^2 + \frac{1}{560}(z-\omega) \right\} \]
\[
+ b_1 \left\{ \frac{U}{(z-\omega)^4} + \frac{1}{2}(z-\omega)^3 + \frac{5}{36}(z-\omega)^2 + \frac{1}{36}(z-\omega) \right\} \\
+ b_2 \left\{ \frac{W}{(z-\omega)^4} + \frac{1}{2}(z-\omega)^3 + \frac{5}{36}(z-\omega)^2 + \frac{1}{36}(z-\omega) \right\} \\
+ b_3 \left\{ \frac{G}{(z-\omega)^2} + \frac{1}{2}(z-\omega) \right\} + b_4 \left\{ \frac{A}{(z-\omega)^2} + \frac{1}{2}(z-\omega) \right\} \\
+ b_5 \left\{ \frac{B}{(z-\omega)^2} + \frac{1}{2}(z-\omega) \right\} + \frac{C/4}{(z-\omega)^8}, \tag{20}
\]

where the composites \( U \) (spin 4), and \( G, A \) and \( B \) (all spin 6), are defined by

\[
U = (TT) - \frac{3}{10}\partial^2 T, \quad G = (\partial^2 TT) - \partial(\partial TT) + \frac{2}{9}\partial^2 (TT) - \frac{1}{42}\partial^4 T, \\
A = (TU) - \frac{1}{6}\partial^2 U, \quad B = (TW) - \frac{1}{6}\partial^2 W, \tag{21}
\]

with normal ordering of products of currents understood. The coefficients \( b_1, b_2, b_3, b_4 \) and \( b_5 \)
are given by
\[ b_1 = \frac{42}{5C + 22}, \quad b_2 = \sqrt{\frac{54(C + 24)(C^2 - 172C + 196)}{(5C + 22)(7C + 68)(2C - 1)}}, \]
\[ b_3 = \frac{3(19C - 524)}{10(7C + 68)(2C - 1)}, \quad b_4 = \frac{24(72C + 13)}{(5C + 22)(7C + 68)(2C - 1)}, \]
\[ b_5 = \frac{28}{3(C + 24)}b_2. \quad (22) \]

These relations determine the coefficients of the terms in \( W_M \), the result turns out to be very simple as follows:
\[ C_M = 1, \quad (23) \]
\[ W_M = \frac{1}{72\sqrt{6}}(\partial^3Y_1Y_1 - 9\partial^2Y_1\partial Y_1 + 84\partial Y_1Y_1\partial Y_2Y_2 + \partial^3Y_2Y_2 - 9\partial^2Y_2\partial Y_2). \quad (24) \]

Substituting these results into (12) gives the final spinor field realization of the non-critical \( W_{2,4} \) string.

5. Conclusion

In this paper, the spinor field realizations of non-critical \( W_{2,s} \) strings have been studied. We have discussed the cases of \( s = 3, 4 \) in detail and constructed the \( BRST \) charges for \( s = 4 \) by explicit computation. The construction was based on demanding nilpotence of the \( BRST \) charges, making no reference to whether or not an underlying \( W_{2,s} \) algebra exists. These solutions are very standard, that is, there are three solutions for \( s = 3 \) and \( 4 \), respectively. We find that the OPE of the spin-3 current with itself gives rise only to a null current, so the two-spinor non-critical realization of \( W_{2,3} \) string is believed not to exist. For the case \( s = 4 \), \( W_M \) has one simple solution. Of course more spinor realizations of \( W_{2,s} \) strings can be calculated with our procedure. We expect that there should exist such realizations with higher spin \( s \). Having obtained the non-critical abstract \( BRST \) charges for \( W_{2,s} \) strings, we can investigate the implications for the corresponding string theories.

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