Finite Nilpotent Symmetry in Field/Antifield Formulation

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Preface

- BRST symmetry is characterized by anticommuting, infinitesimal,global(space time and field independent)
- We showed such infinitesimal transformation can be integrated in consistent manner to construct FFBRST transformation where the parameter is finite field dependent (no explicit space time dependence)
- FFBRST leaves S_{eff} invariant; but not the generating functional
- We showed that this transformation can be the symmetry of generating functional in the extended theory like field/antifield formulation

Plan of the Talk

- Introduction
- Finite BRST Transformations.
- Field/Antifield Formulation.
- Finite BRST in Field/Antifield Formulation.
- FF-anti-BRST in Field/Antifield Formulation.
- Conclusions.

BRST Transformation

BRST transformation for pure Yang-Mills theory:

$$
\begin{aligned}
\delta A_\mu^\alpha &= D_\mu^{\alpha\beta} c^\beta \delta\Lambda \\
\delta c^\alpha &= -\frac{g}{2} f^{\alpha\beta\gamma} c^\beta c^\gamma \delta\Lambda \\
\delta \bar{c}^\alpha &= \frac{F[A]}{\lambda} \delta\Lambda
\end{aligned}
\qquad (1)
$$

Properties

- S_{eff}^{FP} **is symmetric under these transformations.**
- **The PI measure** $\mathcal{D}A_\mu^\alpha \mathcal{D}c^\alpha \mathcal{D}\bar{c}^\alpha$ **is invariant.**
- **Nilpotent, i.e.** $\delta^2 A_\mu^\alpha = 0; \;\; \delta^2 c^\alpha = 0$

BRST Transformation

BRST transformations are extremely important tool in characterizing various renormalizable field theoretic models and renormalization of gauge theories are known to be greatly facilitated by the use of BRST transformation, as these enable one to formulate ST identities in a compact and mathematically convenient form,

$$\mathcal{G}\Gamma[< A >, < c >, < \bar{c} >] = 0.$$

Γ is generating functional for proper vertices and $\mathcal{G}^2 = 0$

A renormalizable Lagrangian that obeys BRST invariance must take the form $S = S_0 + s\psi$. For the complete proof of the renormalization one has to show that UV divergent terms are BRST invariant.

BRST Cohomology

The BRST charge is Nilpotent, $Q^2 = 0$ and Conserved, $[H, Q] = 0$. In BRST formulation, the physical states are defined as,

$$Q|\phi_{phy}>= 0.$$

Now we can have three different subspace,

$$\begin{aligned} H_1 &= \{|\psi_1>;\ Q|\psi_1>\neq 0\} \\ H_2 &= \{|\psi_2>;\ |\psi_2>= Q|\psi_1>\} \\ H_3 &= \{|\psi_3>;\ |\psi_3>\neq Q|\psi_1>\} \end{aligned} \tag{2}$$

ψ_1 are not physical, ψ_2 have zero norms. All important physics are contained in the section H_3. The states of this subspace consist BRST cohomology.

FFBRST Transformation

If we observe the usual BRST transformation and its properties carefully, we notice that the properties of infinitesimal BRST do not depend on whether,

- The parameter is finite or infinitesimal
- The parameter is field dependent or not

as long as the parameter is anti-commuting and explicit space-time independent. Therefore we have liberty to choose parameter finite and field dependent. We integrate the infinitesimal BRST to construct finite field dependent BRST [FFBRST]

Construction of FFBRST

We consider the fields as a function of the parameter $\kappa : 0 \leq \kappa \leq 1$. For a field $\phi(x,\kappa), \phi(x,0) \equiv \phi(x),\ \phi(x,\kappa = 1) \equiv \phi'(x)$. Then the usual infinitesimal BRST transformations can be written as,

$$\frac{d}{d\kappa}\phi(\kappa) = \delta_{BRST}[\phi(\kappa)]\Theta'[\phi(\kappa)]$$

It can be shown that $\Theta'[\phi(\kappa)]$ always contains a factor $\Theta'[\phi(0)]$, and we take that to be nilpotent quantity.
Because of this fact, the above equation can be written as,

$$\frac{d}{d\kappa}\phi(\kappa) = \delta_{BRST}[\phi(0)]\Theta'[\phi(\kappa)]$$

SDJ& BPM, PRD 51, 1919

Construction of FFBRST

The above equation can be integrated immediately to obtain,

$$\phi(\kappa) = \phi(0) + \delta_{BRST}[\phi(0)] \int_0^{\kappa} \Theta'[\phi(\kappa) d\kappa'$$

that is

$$\phi(\kappa) = \phi(0) + \delta_{BRST}[\phi(0)]\Theta[\phi(\kappa), \kappa]$$

where

$\Theta[\phi(\kappa), \kappa]$ **is defined as**

$$\Theta[\phi(\kappa), \kappa] = \int \Theta'[\phi(\kappa)] d\kappa$$

Putting $\kappa = 1$ we obtain the general form of the

$$\phi'(x) = \phi(x) + \delta_{BRST}[\phi(x)]\Theta[\phi(x)]$$

FFBRST for Pure YM theory

For a simple theory [Pure YM] FFBRST can be written explicitly as,

$$
\begin{aligned}
\delta A^\alpha_\mu &= D^{\alpha\beta}_\mu c^\beta \Theta[A^\alpha_\mu, c^\alpha, \bar{c}^\alpha] \\
\delta c^\alpha &= -\frac{g}{2} f^{\alpha\beta\gamma} c^\beta c^\gamma \Theta[A^\alpha_\mu, c^\alpha, \bar{c}^\alpha] \\
\delta \bar{c}^\alpha &= \frac{F[A]}{\lambda} \Theta[A^\alpha_\mu, c^\alpha, \bar{c}^\alpha]
\end{aligned} \tag{3}
$$

Where $\Theta[A^\alpha_\mu, c^\alpha, \bar{c}^\alpha]$ is finite field dependent, anti-commuting and explicit x_μ independent parameter.

What do we mean by finite anti-commuting quantity?

FFBRST ....

Let us consider an example of $\Theta[A, c, \bar{c}]$,

(4) $$\Theta[A, c, \bar{c}] = \int d^4y \bar{c}^\alpha(y) \partial \cdot A^\alpha[y]$$

Now if we calculate the Green's function of $\Theta[A, c, \bar{c}]$ between vacuum and a state with a ghost and a gauge field it has finite value [as opposed to infinitesimal].

Presence of $\bar{c}$ in $\Theta[A, c, \bar{c}]$ makes it nilpotent .

Properties of FFBRST

- **FFBRST is also symmetry of the effective action, S_{eff}^{FP}.**
- **Nilpotent, $\delta^2 = 0$**
- **However the PI measure is NOT invariant FFBRST!!**

The PI measure,

$$\mathcal{D}A_\mu^\alpha \mathcal{D}c^\alpha \mathcal{D}\bar{c}^\alpha = \mathcal{D}A_\mu^{\alpha\prime} \mathcal{D}c^{\alpha\prime} \mathcal{D}\bar{c}^{\alpha\prime} J[A', c', \bar{c}']$$

Hence the generating functional,

$$Z = \int \mathcal{D}A_\mu^\alpha \mathcal{D}c^\alpha \mathcal{D}\bar{c}^\alpha e^{iS_{eff}}$$

is not invariant under FFBRST.

Finite BRST...

It has been shown that the Jacobian, $J[A, c, \bar{c}]$ can always be replaced by $e^{iS_1[A,c,\bar{c}]}$ iff

$$\int \mathcal{D}\phi(\kappa)[\frac{1}{J}\frac{dJ}{d\kappa} - i\frac{dS_1}{d\kappa}]e^{iS_1+iS_{eff}} = 0$$

Where $S_1[A, c, \bar{c}]$ is local functional of fields and can be considered as part of the action.

$$S'_{eff} = S_1 + S_{eff}$$

An example:

$$\int \mathcal{D}A_\mu^\alpha \mathcal{D}c^\alpha \mathcal{D}\bar{c}^\alpha \; e^{iS^L_{eff}} \longrightarrow \int \mathcal{D}A_\mu^\alpha \mathcal{D}c^\alpha \mathcal{D}\bar{c}^\alpha \; e^{i(S^L_{eff}+S_1)}$$

FFBRST....

Where S_1 **depends on the choice of the FFBRST parameter** $\Theta[A, c, \bar{c}]$**. By constructing [Non-trivial job!!] different** $\Theta[A, c, \bar{c}]$ **we can obtain different effective actions. For Example If we take a**

$$\Theta'[A, c, \bar{c}] = i \int d^4 y \bar{c}^\alpha [\partial \cdot A^\alpha - \eta \cdot A^\alpha]$$

then S_1 **will be,**

$$S_1 = \int d^4 x [-\frac{1}{2}(\eta \cdot A^\alpha)^2 + \frac{1}{2}(\partial \cdot A^\alpha)^2 - \partial_\mu \bar{c}^\alpha D^{\alpha\beta\mu} c^\beta + \eta_\mu \bar{c}^\alpha D^{\alpha\beta\mu} c^\beta]$$

$$S^L_{eff} + S_1 = S^A_{eff}$$

By choosing the suitable parameter $\Theta[A, c, \bar{c}]$ **we can connect any pair of effective theories.**

APPLICATIONS of FFBRST

- Prescriptions for the singularities in the axial guage propagator

In axial gauge, the gauge field propagator has singularity of the type $\frac{1}{(\eta\cdot k)^\beta}$. Any calculation involving gauge field propagator we need some prescription to tackle the singularities.

Commonly used prescriptions are:

- Principal Value Prescription **[PVP]**,
- Mandelstam - Leibbrandt Prescription **[MLP]**.

Prescription Problems

However, these prescriptions are adhoc and lead to variety of problems.

- **PVP violets WT identity to one loop order,**
- **MLP leads to Lorentz non-invariant integral and/or nonlocal counter terms**

FFBRST is used to find the solution for the prescription problem.

Prescription Problems

We know the $\frac{1}{k^2}$ singularities of the propagator are handled in Lorentz gauge by replacing k^2 by $k^2 + i\epsilon$.

This is equivalent to a term, $-\epsilon \int d^4x[\frac{A_\mu A^\mu}{2} - \bar{c}c]$ in the action.

Now we apply FFBRST which converts the theory in Lorentz gauge to axial gauge theory.

That is by choosing the FFBRST parameter,

$$\Theta'[A, c, \bar{c}] = i \int d^4y \bar{c}^\alpha [\partial \cdot A^\alpha - \eta \cdot A^\alpha]$$

We obtained a modified propagator in the axial gauge theory where singularity is taken care of.

Coulomb Gauge Problem

The time like propagator in Coulomb gauge, $D_{00} = \frac{1}{|k|^2}$ is not damped as $k_0 \to \infty$ limit. Hence the energy integral, $\int dk_0$ become divergent in 2nd or higher loop calculations.
This kind of divergent can not be regularized in dimensional regularization.
We have solved this problem by relating the theory at Covariant gauge $[\partial_\mu A^\mu = 0]$ to theory at Coulomb gauge $[\partial_i A^i = 0]$ through FFBRST transformation.

We know that proper definition of Green's functions in Lorentz gauges is not possible unless we include a term $-\epsilon \int d^4x[\frac{1}{2}A_\mu A^\mu - c\bar{c}]$ in the effective action.

Coulomb Gauge Problem

Similarly the proper definition of Coulomb gauge Green's functions require appropriate ϵ dependent term and this is expected to tell us how the Coulomb propagator should be handled.
The correct ϵ term is automatically obtained by FFBRST transformations which connect Lorentz gauge theory to Coulomb gauge theory.

SDJ & BPM, IJMPA 17, 1579 (2002)

Field/Antifield formulation

Batalin & Vilkovisky addressed the question, given a set of classical fields $\phi^i(x)$ and a classical action $S[\phi^i]$, what is the full quantum action $W(\phi)$ such that the functional integral

$$Z[J] = \int \mathcal{D}\phi \, e^{iW(\phi)+J(\phi)}$$

determines all physical quantities.

To answer this question they extended the action, $W(\phi, \phi^*)$ by introducing antifield, ϕ^*, corresponding to each field ϕ with opposite statistic. Generically ϕ denotes all the fields involved in the theory. The sum of ghost number associated to a field and its antifield is equal to -1.

Field/Antifield formulation

This extended quantum action satisfies certain rich mathematical relation called quantum master equation

(5) $$\Delta e^{iW[\phi,\phi^*]} = 0 \ \textbf{ with } \ \Delta \equiv \frac{\partial_r}{\partial\phi}\frac{\partial_r}{\partial\phi^*}(-1)^{\epsilon+1}.$$

Master equation reflects the gauge symmetry in the zeroth order of antifields and in the first order of antifields it reflects nilpotency of BRST transformation. This equation can also be written in terms of antibrackets as,

(6) $$(W, W) = 2i\Delta W,$$

Field/Antifield formulation

where the antibracket is defined as

$$(X,Y) \equiv \frac{\partial_r X}{\partial \phi}\frac{\partial_l Y}{\partial \phi^*} - \frac{\partial_r X}{\partial \phi^*}\frac{\partial_l Y}{\partial \phi}. \tag{7}$$

Different effective actions belonging to the same theory are solutions of master equations.

Field/Antifield formulation

The generating functional can be written as

$$Z[\Phi^\star] = \int D\Phi e^{iW_\Psi\left[\Phi,\Phi^*=\frac{\partial\Psi}{\partial\Phi}\right]}, \tag{8}$$

Ψ **is the gauge fixed fermion and has Grassman parity 1 and ghost number -1. The antifields are defined as**

$$\Phi^* = \frac{\delta\Psi}{\delta\Phi} \tag{9}$$

The generating functional, $Z[\Phi^*]$ **is independent of the choice of** Ψ

Field/Antifield formulation

We have constructed FFBRST transformation by chosing appropriate finite parameter in such a way that Jacobian contribution in the path integral measure only changes the gauge fixed fermions.

Thus FFBRST with appropriate finite parameter will not change the generating functional as it is independent of the choice of the gauge fixed fermions

We have shown this in 1-form as well as in 2-form gauge theories by considering several explicit examples.

Field/Antifield : In 1-form theory

We start with the generating functional of YM theory in Lorentz gauge as

$$Z^L = \int D\phi \exp\left[iS_{eff}(A, c, \bar{c}, B)\right], \tag{10}$$

where $S_{eff}(A, c, \bar{c}, B)$, **is given by**

$$\begin{aligned} S_{eff}(A, c, \bar{c}, B) = \int d^4x [& - \frac{1}{4} F^{\alpha\mu\nu} F^{\alpha}_{\mu\nu} + \frac{\lambda}{2}(B^\alpha)^2 - B^\alpha \partial \cdot A^\alpha \\ & - \bar{c}^\alpha \partial^\mu D^{\alpha\beta}_\mu c^\beta] \end{aligned} \tag{11}$$

Here we have considered auxiliary field formulation of YM theory and need to extend the FFBRST formulation in auxiliary field formulations

Field/Antifield : In 1-form theory

This generating functional can be expressed in field/antifield formulation as

$$
\begin{aligned}
Z^L &= \int [dAdcd\bar{c}dB] \exp\left[i \int d^4x \left\{ -\frac{1}{4} F^{\alpha\mu\nu} F^{\alpha}_{\mu\nu} + A^{\mu\alpha *} D^{\alpha\beta}_{\mu} c^{\beta} \right.\right. \\
&\quad \left.\left. + \, c^{\alpha *} \frac{g}{2} f^{\alpha\beta\gamma} c^{\beta} c^{\gamma} + B^{\alpha} \bar{c}^{\alpha *} \right\} \right],
\end{aligned} \tag{12}
$$

Field/Antifield : In 1-form theory

The generating functional in 1-form gauge theory can be written compactly as,

(13) $$Z[\Phi^*] = \int D\Phi \exp\left[iW_\Psi(\Phi, \Phi^*)\right],$$

where

(14) $$W_\Psi = S_0(\Phi) + \delta_{brst}\Psi.$$

Ψ **is the gauge fixed fermion and can be written in this case as**

(15) $$\Psi = \int d^4x \; \bar{c}^\alpha \left[\frac{\lambda}{2}B^\alpha - \partial \cdot A^\alpha\right].$$

We construct the finite field dependent parameter $\Theta(A, c, \bar{c}, B)$ **obtainable from**

In 1- form theories

(16) $$\Theta'(A, c, \bar{c}, B) = i \int d^4y\ \bar{c}^\alpha \left[\gamma_1 \lambda B^\alpha + (\partial \cdot A^\alpha - \eta \cdot A^\alpha)\right],$$

and apply FFBRST corresponding to this parameter which change the generating functional $Z[\Phi^*]$ to $Z[\tilde{\Phi}^*]$ given as

(17) $$Z[\tilde{\Phi}^*] = \int D\Phi \exp\left[iW_{\Psi_1}(\Phi, \tilde{\Phi}^*)\right],$$

(18) $$W_{\Psi_1} = S_0(\Phi) + \delta_{brst}\Psi_1,$$

with $\tilde{\Phi}^* = \frac{\delta\Psi_1}{\delta\Phi}$. The gauge fixed fermion is changed from $\Psi \rightarrow \Psi_1$ given as

(19) $$\Psi_1 = \int d^4x\ \bar{c}^\alpha \left[\frac{\xi}{2} B^\alpha - \eta \cdot A^\alpha\right],$$

1-form theories ....

with $\xi = \lambda(1 + 2\gamma_1)$.
However $Z[\tilde{\Phi}^*]$ is independent of the choice of Ψ

$$Z[\Phi^*] - - - - - \overset{FFBRST}{- - - - - - -} \longrightarrow Z[\tilde{\Phi}^*] \tag{20}$$

Implies that FFBRST transformation with above choice of the finite parameter is symmetry of the generating functional.

However this choice is not unique, we can construct, in principle, many such finite parameter and corresponding FFBRST will be the symmetry of generating functional in BV formulation.

1-form theories ....

Another choice:

(21) $$\Theta'(A, c, \bar{c}, B) = i \int d^4y\ \bar{c}^\alpha \left[\gamma_1 \lambda B^\alpha + \partial_0 A_0^\alpha\right],$$

the generating functional $Z[\Phi^\star]$ changes to

(22) $$Z[\tilde{\Phi}^*] = \int D\Phi \exp\left[iW_{\Psi_2}(\Phi, \tilde{\Phi}^*)\right],$$

where Ψ_2 is the gauge fixed fermion given as

(23) $$\Psi_2 = \int d^4x\ \bar{c}^\alpha \left[\frac{\xi}{2} B^\alpha - \partial^i A_i^\alpha\right],$$

1-form theories ....

(24) $$Z[\Phi^*] \quad \xrightarrow[FFBRST with]{\Theta'} \quad Z[\tilde{\Phi}^*]$$

BPM, SKR & SU, Europhysics Lett. 92, 21001 (2010)

2-form gauge theory

The effective action for Abelian gauge theory for rank-2 antisymmetric tensor field $B_{\mu\nu}$ defined as

$$\begin{aligned} S &= \int d^4x \left[\frac{1}{12} F_{\mu\nu\rho} F^{\mu\nu\rho} - i \partial_\mu \tilde{\rho}_\nu (\partial^\mu \rho^\nu - \partial^\nu \rho^\mu) + \partial_\mu \tilde{\sigma} \partial^\mu \sigma \right. \\ &+ \left. \beta_\nu (\partial_\mu B^{\mu\nu} + \lambda_1 \beta^\nu - \partial^\nu \varphi) - i \tilde{\chi} \partial_\mu \rho^\mu - i \chi (\partial_\mu \tilde{\rho}^\mu - \lambda_2 \tilde{\chi}) \right], \end{aligned}$$

where $F_{\mu\nu\lambda} = \partial_\mu B_{\nu\lambda} + \partial_\nu B_{\lambda\mu} + \partial_\lambda B_{\mu\nu}$,
$B_{\mu\nu}$ is the antisymmetric tensor field of rank-2,
$(\rho_\mu, \tilde{\rho}_\mu)$ are anticommuting vector fields (ghost), $(\sigma_\mu, \tilde{\sigma}_\mu)$ are commuting fields, $(\chi, \tilde{\chi})$ are anticommuting scalar fields, and (β_μ, φ) are commuting vector and scalar field respectively.

Field/Antifield: 2-form gauge theory

The generating functional for this theory in BV formulation can be written as

$$Z\left[B^{\mu\nu *}, \rho^{\mu *}, \tilde{\rho}^{\mu *}, \tilde{\sigma}^{*}, \varphi^{*}\right] = \int \left[dB d\rho d\tilde{\rho} d\sigma d\tilde{\sigma} d\varphi d\chi d\tilde{\chi} d\beta\right] \exp\left[i\int d^4x \left\{\frac{1}{12}F_{\mu\nu\lambda}F^{\mu\nu\lambda} - B^{\mu\nu\star}\left(\partial_\mu\rho_\nu - \partial_\nu\rho_\mu\right) - i\ \rho^{\mu\star}\partial_\mu\rho + i\tilde{\rho}^{\nu\star}\beta_\nu - \tilde{\sigma}^{\star}\tilde{\chi} - \varphi^{\star}\chi\right\}\right]. \tag{25}$$

Field/Antifield: 2-form gauge theory

The generating functional can be expressed compactly as

(26) $$Z[\Phi^*] = \int D\Phi \exp\left[iW_{\Psi_3}(\Phi, \tilde{\Phi}^\star)\right],$$

where

(27) $$W_{\Psi_3} = S_0(\Phi) + \delta_{brst}\Psi_3.$$

Ψ_3 is the gauge fixed fermion given as

$$\Psi_3 = -i\int d^4x\,[\tilde{\rho}_\nu\,(\partial_\mu B^{\mu\nu} + \lambda_1\beta^\nu) + \tilde{\sigma}\partial_\mu\rho^\mu + \varphi\,(\partial_\mu\tilde{\rho}^\mu - \lambda_2\tilde{\chi})]\,.$$

(28)

The antifields $\Phi^\star$ corresponding to generic field Φ for this particular theory can be obtained from the gauge fixed fermion using $\tilde{\Phi}^\star = \frac{\delta\Psi_3}{\delta\Phi}$.

2-Form gauge theory

Now we choose a FFBRST parameter corresponding to

$$
\begin{aligned}
\Theta' &= \int d^4x\, [\gamma_1 \tilde{\rho}_\nu (\partial_\mu B^{\mu\nu} - \eta_\mu B^{\mu\nu} - \partial^\nu \varphi - \eta^\nu \varphi) + \gamma_2 \lambda_1 \tilde{\rho}_\nu \beta^\nu \\
&+ \gamma_1 \tilde{\sigma} (\partial_\mu \rho^\mu - \eta_\mu \rho^\mu) + \gamma_2 \lambda_2 \tilde{\sigma} \chi] \qquad (29)
\end{aligned}
$$

and apply it to Z$[\Phi^\star]$ **to get** $Z[\tilde{\Phi}^\star]$ **where**

$$
\begin{aligned}
Z[\tilde{\Phi}^\star] &= \int D\phi \exp[i W_{\Psi_4}(\Phi, \tilde{\Phi}^\star], \\
W_{\Psi_4} &= S_0(\Phi) + \delta_{brst} \Psi_4, \\
\Psi_4 &= -i \int d^4x\, [\tilde{\rho}_\nu \left(\eta_\mu B^{\mu\nu} + \lambda_1 \beta^\nu\right) + \tilde{\sigma} \eta_\mu \rho^\mu + \varphi \left(\eta_\mu \tilde{\rho}^\mu - \lambda_2 \tilde{\chi}\right)
\end{aligned}
$$

FFAnti-BRST

- **Anti-BRST transformations are analogous to BRST transformations where the role of ghosts and anti-ghosts fields are interchanged**

Anti-BRST transformation for pure Yang-Mills theory:

$$\begin{aligned} \delta A_\mu^\alpha &= D_\mu^{\alpha\beta}\bar{c}^\beta \delta\Lambda \\ \delta\bar{c}^\alpha &= -\frac{g}{2} f^{\alpha\beta\gamma}\bar{c}^\beta\bar{c}^\gamma \delta\Lambda \\ \delta c^\alpha &= \frac{F[A]}{\lambda}\delta\Lambda \end{aligned} \quad (30)$$

FFAnti-BRST

- **Formal nilpotent symmetry transformations for the generating functional in field/antifield formulation can also be constructed using FFanti-BRST transformations.**

For a simple theory [Pure YM] FFBRST can be written explicitly as,

$$\begin{aligned} \delta A_\mu^\alpha &= D_\mu^{\alpha\beta}\bar{c}^\beta \Theta[A_\mu^\alpha, c^\alpha, \bar{c}^\alpha] \\ \delta \bar{c}^\alpha &= -\frac{g}{2} f^{\alpha\beta\gamma}\bar{c}^\beta \bar{c}^\gamma \Theta[A_\mu^\alpha, c^\alpha, \bar{c}^\alpha] \\ \delta c^\alpha &= \frac{F[A]}{\lambda}\Theta[A_\mu^\alpha, c^\alpha, \bar{c}^\alpha] \end{aligned} \tag{31}$$

FFAnti-BRST:One form

- **FFanti-BRST transformations with finite field dependent parameter corresponding to**

(32) $$\Theta' = -i\gamma \int d^4x\, c^\alpha(\partial\cdot A^\alpha - \partial_j A^{j\alpha})$$

changes the gauge fixed fermion only and becomes the symmetry of the generating functional for 1-form theory in field/antifield formulation

(33) $$Z[\Phi^*] - - - - - \overset{FFBRST}{-} - - - - - -- \longrightarrow Z[\tilde{\Phi}^*]$$

Finite anti-BRST:Two form

In 2-form gauge theory we can construct the finite field anti-BRST transformations parameter corresponding to

$$\Theta'_{ab} = -\int d^4x\,[\gamma_1\rho_\nu(\partial_\mu B^{\mu\nu} - \eta_\mu B^{\mu\nu} - \partial^\nu\varphi - \eta^\nu\varphi) + \gamma_2\lambda_1\rho_\nu\beta^\nu$$
$$- \quad \gamma_1\sigma(\partial_\mu\tilde{\rho}^\mu - \eta_\mu\tilde{\rho}^\mu) + \gamma_2\lambda_2\sigma\tilde{\chi}]\,, \tag{34}$$

is the symmetry generating functional in BV formulation of 2-form gauge theory. Thus, FFanti-BRST transformations with appropriate parameters are also the symmetry of the generating functional BV formulation.

Conclusions

- FFBRST transformation which relates generating functional in usual gauge theories are shown to be the symmetry of the generating functional in the field/antifield formulation.
- The finite parameter is chosen in such a way that the Jacobian in the path integral measure is adjusted to change the gauge fixed fermions only.
- Results are shown to be valid in both 1-form and 2-form gauge theories.
- FFanti-BRST transformation is also constructed and it plays the same role as FFBRST

Conclusions: Future directions

- **Gribov Problem: By connecting the theory free from Gribov ambiguity (Gribov-Zwanziger theory) to a theory with Gribov copies**
- **Ambiguity in anomalous dimension calculations**
- **Gauge independence among the families of gauges**
- In finite temperature field theory

THANK YOU