A Local Equivariant Index Theorem for Sub-Signature Operators

Kaihua Bao, Jian Wang, Yong Wang

1 School of Mathematics and Physics, Inner Mongolia University for Nationalities, Tongliao, 028005, P.R. China
2 School of Science, Tianjin University of Technology and Education, Tianjin, 300222, P.R. China
3 School of Mathematics and Statistics, Northeast Normal University, Changchun, 130024, P.R. China

ABSTRACT

In this paper, we prove a local equivariant index theorem for sub-signature operators which generalizes Weiping Zhang's index theorem for sub-signature operators.

1. INTRODUCTION

The Atiyah-Singer index Theorem ([2,3]) gives a cohomological interpretation of the Fredholm index of an elliptic operator. The Atiyah-Bott-Segal-Singer index formula, which called the equivariant index theorem, is a generalization with group action of the Atiyah-Singer index theorem. The first direct proof of this result was given by Patodi, Gilkey, Atiyah-Bott-Patodi partly by using invariant theory [1,12]. This theorem generalizes the Atiyah-Singer index theorem and the Atiyah-Bott fixed point formula for elliptic complexes, which is a generalization of the Lefschetz fixed point formula. In [7], Berline and Vergne gave a heat kernel proof of the Atiyah-Bott-Segal-Singer index formula. Moreover, Lafferty, Yu and Zhang [14] presented a simple and direct geometric proof of the equivariant index theorem for an orientation-preserving isometry on an even dimensional spin manifold by using Clifford asymptotics of heat kernel. Furthermore, Ponge and H. Wang gave a different proof of the equivariant index formula by the Greiner's approach to the heat kernel asymptotics [19]. In [15], in order to prove family rigidity theorems, Liu and Ma proved the equivariant fixed point formula. In [22], Y. Wang gave another proof of the local equivariant index theorem for a family of Dirac operators by the Greiner's approach to the heat kernel asymptotics. In [21], using the Greiner's approach to the heat kernel asymptotics, Y. Wang proved the equivariant Gauss-Bonnet-Chern formula and gave the variation formulas for the equivariant Ray-Singer metric, which are originally due to J. M. Bismut and W. Zhang [9].

In parallel, Freed [11] considered the case of an orientation reversing involution acting on an odd dimensional spin manifold and gave the associated Lefschetz formulas by the K-theretical way. In [20], Wang constructed an even spectral triple by the Dirac operator and the orientation-reversing involution and computed the Connes-Chern character for this spectral triple. In [16], Liu and Wang proved an equivariant odd index theorem for Dirac operators with involution parity and the Atiyah-Hirzebruch vanishing theorems for odd dimensional spin manifolds. In [24] and [23], Zhang introduced the sub-signature operators and proved a local index formula for these operators. By computing the adiabatic limit of eta-invariants associated to the so-called sub-signature operators, a new proof of the Riemann-Roch-Grothendieck type formula of Bismut-Lott was given in [17] and [10]. The motivation of the present article is to prove a local equivariant index formula for sub-signature operators. As the subsignature operator is locally a twisted Dirac operator, we can obtain our theorem by the proof of equivariant twisted Dirac operators. We give a direct proof of a local equivariant index theorem for subsignature operators by the Volterra calculus, rather than derived from the local equivariant index theorem of twisted Dirac operators. Thus our direct proof of the equivariant index theorem of the subsignature operators using Volterra calculus can be seen as analogous to the works [21,23,26].

In parallel, Freed [11] considered the case of an orientation reversing involution acting on an odd dimensional spin manifold and gave the associated Lefschetz formulas by the K-theretical way. In [20], Wang constructed an even spectral triple by the Dirac operator and the orientation-reversing involution and computed the Connes-Chern character for this spectral triple. In [16], Liu and Wang proved an equivariant odd index theorem for Dirac operators with involution parity and the Atiyah-Hirzebruch vanishing theorems for odd dimensional spin manifolds. In [24] and [23], Zhang introduced the sub-signature operators and proved a local index formula for these operators. By computing the adiabatic limit of eta-invariants associated to the so-called sub-signature operators, a new proof of the Riemann-Roch-Grothendieck type formula of Bismut-Lott was given in [17] and [10]. The motivation of the present article is to prove a local equivariant index formula for sub-signature operators. As the subsignature operator is locally a twisted Dirac operator, we can obtain our theorem by the proof of equivariant twisted Dirac operators. We give a direct proof of a local equivariant index theorem for subsignature operators by the Volterra calculus, rather than derived from the local equivariant index theorem of twisted Dirac operators. Thus our direct proof of the equivariant index theorem of the subsignature operators using Volterra calculus can be seen as analogous to the works [21,23,26].

This paper is organized as follows: In Section 2, we recall some background on sub-signature operators. In Section 3.1, we prove a local equivariant index formula for sub-signature operators in even dimension. In Section 3.2, we prove a local equivariant odd dimensional index formula for sub-signature operators with an orientation-reversing involution.

*Corresponding author: Email: wangy581@nenu.edu.cn

Data availability statement: The authors confirm that the data supporting the findings of this study are available within the article.
2. THE SUB-SIGNATURE OPERATORS

In this section, we give the standard setup (also see Section 1 in [24]). Let \( M \) be an oriented closed manifold of dimension \( n \). Let \( E \) be an oriented sub-bundle of the tangent vector bundle \( TM \). Let \( g^{TM} \) be a metric on \( TM \). Let \( g^E \) be the induced metric on \( E \). Let \( E^\perp \) be the sub-bundle of \( TM \) orthogonal to \( E \) with respect to \( g^{TM} \). Let \( g^{E^\perp} \) be the metric on \( E^\perp \) induced from \( g^{TM} \). Then \((TM, g^{TM})\) has the following orthogonal splittings

\[
TM = E \oplus E^\perp, \tag{2.1}
\]
\[
g^{TM} = g^E \oplus g^{E^\perp}. \tag{2.2}
\]

Clearly, \( E^\perp \) carries a canonically induced orientation. We identify the quotient bundle \( TM/E \) with \( E^\perp \).

Let \( \Omega(M) = \bigoplus_{k=0}^n \Omega^k(M) = \bigoplus_{k=0}^n \Gamma(T^*(M)) \) be the set of smooth sections of \( \wedge(T^*M) \). Let \( * \) be the Hodge star operator of \( g^{TM} \). Then \( \Omega(M) \) inherits the following inner product

\[
\langle \alpha, \beta \rangle = \int_M \alpha \wedge g^{TM} \beta, \quad \alpha, \beta \in \Omega(M). \tag{2.3}
\]

We use \( g^{TM} \) to identify \( TM \) and \( T^*M \). For any \( e \in \Gamma(TM) \), let \( c \wedge \) and \( i_\cdot \) be the standard notation for exterior and interior multiplications on \( \Omega(M) \). Let \( c(e) = e \wedge \cdot, \tilde{c}(e) = e \wedge + \cdot \) be the Clifford actions on \( \Omega(M) \) verifying that

\[
c(e)c(e') + c(e')c(e) = -2\langle e, e' \rangle g^{TM}, \tag{2.4}
\]
\[
\tilde{c}(e)c(e') + \tilde{c}(e')\tilde{c}(e) = 2\langle e, e' \rangle g^{TM}, \tag{2.5}
\]
\[
c(e)\tilde{c}(e') + \tilde{c}(e')c(e) = 0. \tag{2.6}
\]

Denote \( k = \dim E \) and we assume \( k \) is even. Let \( \{f_1, \ldots, f_k\} \) be an oriented (local) orthonormal basis of \( E \). Set

\[
\hat{c}(E, g^E) = \hat{c}(f_1) \cdots \hat{c}(f_k), \tag{2.7}
\]

where \( \hat{c}(E, g^E) \) does not depend on the choice of the orthonormal basis. Let

\[
\epsilon = \Id_{\wedge^{even}(T^*M)} - \Id_{\wedge^{odd}(T^*M)}
\]

be the \( Z_2 \)-grading operator of

\[
\wedge(T^*M) = \wedge^{even}(T^*M) \oplus \wedge^{odd}(T^*M).
\]

Set

\[
\tau(M, g^E) = \left( \frac{1}{\sqrt{-1}} \right)^{\frac{k(k+1)}{2}} \epsilon \hat{c}(E, g^E). \tag{2.8}
\]

It is easy to check

\[
\tau(M, g^E)^2 = 1. \tag{2.9}
\]

Let

\[
\wedge_{\pm}(T^*M, g^E) = \big\{ \omega \in \wedge(T^*M), \tau(M, g^E)\omega = \pm \omega \big\}
\]

the (even/odd) eigen-bundles of \( \tau(M, g^E) \) and by \( \Omega_{\pm}(M, g^E) \) the corresponding set of smooth sections. Let \( \delta = d^* \) be the formal adjoint operator of the exterior differential operator \( d \) on \( \Omega(M) \) with respect to the inner product \( (2.3) \). Set on \( \Omega(M) = \Gamma(A T^*M) \)

\[
D_E = \frac{1}{2} \left( \hat{c}(E, g^E) (d + \delta) + (-1)^k (d + \delta) \hat{c}(E, g^E) \right). \tag{2.10}
\]

Then we can check

\[
D_E \tau(M, g^E) = -\tau(M, g^E) D_E, \tag{2.11}
\]
\[
D_E^* = (-1)^{\frac{k(k+1)}{2}} D_E, \tag{2.12}
\]

where \( D_E^* \) is the formal adjoint operator of \( D_E \) with respect to the inner product \( (2.3) \). Set

\[
\tilde{D}_E = (\sqrt{-1})^{\frac{k(k+1)}{2}} D_E.
\]

From \( (2.11) \), \( \tilde{D}_E \) is a formal self-adjoint first order elliptic differential operator on \( \Omega(M) \) interchanging \( \Omega_{\pm}(M, g^E) \).

**Definition 2.1.** The sub-signature operator \( \tilde{D}_{E^+} \) with respect to \((E, g^{TM})\) is the restriction of \( \tilde{D}_E \) on \( \Omega_{+}(M, g^E) \).
If we denote the restriction of $\tilde{D}_E$ on $\Omega_\pm(M, g^E)$ by $\tilde{D}_{E, \pm}$, then

$$\tilde{D}_{E, \pm} = \tilde{D}_{E, \mp}.$$  

Recall that $E$ is the subbundle of $TM$ and that we have the orthogonal decomposition (2.1) of $TM$ and the metric $g^TM$. Let $p^E$ (resp. $p^{E^\perp}$) be the orthogonal projection from $TM$ to $E$(resp. $E^\perp$). Let $\nabla^{TM}$ be the Levi-Civita connection of $g^{TM}$. We will use the same notation for its lift to $\Omega(M)$. Set

$$\nabla^E = p^E \nabla^{TM} p^E,$$

$$\nabla^{E^\perp} = p^{E^\perp} \nabla^{TM} p^{E^\perp}. \quad (2.13)$$

Then $\nabla^{E^\perp}$ is a Euclidean connection on $E$(resp.$E^\perp$), and we will use the same notation for its lifting on $\Omega(E^*)$(resp. $\Omega(E^\perp^*)$). Let $S$ be the tensor defined by

$$\nabla^{TM} = \nabla^E + \nabla^{E^\perp} + S.$$

Then $S$ takes values in skew-adjoint endomorphisms of $TM$, and interchanges $E$ and $E^\perp$. Let $[e_1, \ldots, e_n]$ be an oriented (local) orthonormal base of $TM$. To specify the role of $E$, set $[f_1, \ldots, f_k]$ be an oriented (local) orthonormal basis of $E$. We will use the greek subscripts for the basis of $E$. Then by Proposition 1.4 in [24], we have

**Proposition 2.2.** The following identity holds,

$$\tilde{D}_E = (\sqrt{-1})^{\frac{n(n-1)}{2}} \left( \hat{\zeta}(E, g^E)(d + \delta) + \frac{1}{2} \sum_i c(i)(\nabla^E \hat{\zeta}(E, g^E)) \right). \quad (2.15)$$

Similar to Lemma 1.1 in [24], we have

**Lemma 2.3.** For any $X \in \Gamma(TM)$, the following identity holds,

$$\nabla^X \hat{\zeta}(E, g^E) = -\hat{\zeta}(E, g^E) \sum_a \hat{\zeta}(S(X)f_a) \hat{\zeta}(f_a). \quad (2.16)$$

Let $\Delta^{TM}$, $\Delta^E$ be the Bochner Laplacians

$$\Delta^{TM} = \sum_i (\nabla^E_{\tilde{e}_i}^2 - \nabla^E_{\tilde{e}_i})$$

$$\Delta^E = \sum_i (\nabla^E_{\tilde{e}_i}^2 - \nabla^E_{\tilde{e}_i}). \quad (2.18)$$

Let $K$ be the scalar curvature of $(M, g^{TM})$. Let $R^{TM}$ (resp., $R^E$, $R^{E^\perp}$) be the curvature of $\nabla^{TM}$ (resp., $\nabla^E$, $\nabla^{E^\perp}$). Let $[h_1, \ldots, h_{n-k}]$ be an oriented (local) orthonormal base of $E^\perp$. Now we can state the following Lichnerowicz type formula for $\tilde{D}_E$. From Theorem 1.1 in [24], we have

**Theorem 2.4.** [24] The following identity holds,

$$\tilde{D}_E^2 = -\Delta^{TM} + \frac{K}{4} + \frac{1}{8} \sum_{1 \leq i, j \leq n} \sum_{1 \leq a, \beta \leq k} \langle R^E(e_i, e_j) f_\beta, f_a \rangle c(e_i) c(e_j) \hat{\zeta}(f_a) \hat{\zeta}(f_\beta)$$

$$+ \frac{1}{8} \sum_{1 \leq i, j \leq n} \sum_{1 \leq a, \beta \leq k} \langle R^{E^\perp}(e_i, e_j) h_1, h_3 \rangle c(e_i) c(e_j) \hat{\zeta}(h_3) \hat{\zeta}(h_1) + \frac{1}{2} \sum_a \hat{\zeta}((\Delta^{TM} - \Delta^E)f_a) \hat{\zeta}(f_a)$$

$$+ \sum_{i,a} \hat{\zeta}(S(e_i)f_a) \hat{\zeta}(f_a) \nabla^E_{\tilde{e}_i}^2 - \hat{\zeta}(S(e_i)\nabla^E_{\tilde{e}_i}) \hat{\zeta}(f_a) + \frac{1}{2} \hat{\zeta} \left( \nabla^E_{\nabla^{TM} - \nabla^E} f_a \right) \hat{\zeta}(f_a) + \frac{3}{4} \sum_a \Xi(e_i)f_a \| f_a \|^2$$

$$+ \frac{1}{4} \sum_{i,a \neq \beta} \hat{\zeta}(S(e_i)f_a) \hat{\zeta}(S(e_i)f_\beta) \hat{\zeta}(f_a) \hat{\zeta}(f_\beta). \quad (2.19)$$

### 3. A LOCAL EQUIVARIANT INDEX THEOREM FOR SUB-SIGNATURE OPERATORS

#### 3.1. A Local Even Dimensional Equivariant Index Theorem for Sub-Signature Operators

Let $M$ be a closed oriented Riemannian manifold of even dimension $n$ and $\phi$ an orientation-preserving isometry on $M$. Then the smooth map $\phi$ induces a map $\phi^{-1, \ast} : \wedge^n TM \rightarrow \wedge^n T^\perp_{\phi} M$ on the exterior algebra bundle $\wedge^n TM$. Let $\tilde{D}_E$ be the sub-signature operator. We
We recall the Greiner’s approach to the heat kernel asymptotics as in [19] and [4, 5, 13]. Define the operator given by

\[ \partial_t^2 \] 

\[ \partial_t^2 \] 

\[ \partial_t^2 + \frac{\partial}{\partial t} \]

\[ \partial_t^2 + \frac{\partial}{\partial t} \]

\[ \partial_t^2 + \frac{\partial}{\partial t} \]

The parabolic homogeneity of the heat operator \( \partial_t^2 + \frac{\partial}{\partial t} \) is the heat kernel of \( \partial_t^2 + \frac{\partial}{\partial t} \) as in [5]. Let \( \lambda \cdot (\xi, \tau) = (\lambda \xi, \lambda^2 \tau) \) and \( (\xi, \tau) \in \mathbb{R}^n \times \mathbb{R}^1, \lambda \neq 0 \).

\[ \lambda \cdot (\xi, \tau) = (\lambda \xi, \lambda^2 \tau), \quad (\xi, \tau) \in \mathbb{R}^n \times \mathbb{R}^1, \lambda \neq 0. \] (3.7)

Let \( p_2(x, \xi) + p_1(x, \xi) + p_0(x, \xi) \) be the symbol of \( \partial_t^2 + \frac{\partial}{\partial t} \), then the symbol of \( \partial_t^2 + \frac{\partial}{\partial t} \) is \( \sqrt{\lambda} + p_2(x, \xi) + p_1(x, \xi) + p_0(x, \xi) \), it is homogeneous with respect to \( (\xi, \tau) \).

In the following, for \( g \in S(\mathbb{R}^{n+1}) \) and \( \lambda \neq 0 \), we let \( g_\lambda \) be the tempered distribution defined by

\[ \langle g_\lambda(\xi, \tau), u(\xi, \tau) \rangle = |\lambda|^{-(n+2)} \langle g(\xi, \tau), u(\xi, \tau) \rangle, \quad u \in S(\mathbb{R}^{n+1}). \] (3.8)

**Definition 3.1.** A distribution \( g \in S(\mathbb{R}^{n+1}) \) is parabolic homogeneous of degree \( m \), \( m \in \mathbb{Z} \), if for any \( \lambda \neq 0 \), we have \( g_\lambda = \lambda^m g \).

Let \( \mathbb{C}_- \) denote the complex halfplane \( \text{Im} \rho < 0 \) with closure \( \overline{\mathbb{C}_-} \). Then:

**Lemma 3.2.** [5] Let \( q(\xi, \tau) \in C^\infty((\mathbb{R}^n \times \mathbb{R})/0) \) be a parabolic homogeneous symbol of degree \( m \) such that:

(i) \( q \) extends to a continuous function on \( \mathbb{R}^n \times \mathbb{C}_- \); in such a way to be holomorphic in the last variable when the latter is restricted to \( \mathbb{C}_- \).

Then there is a unique \( g \in S(\mathbb{R}^{n+1}) \) agreeing with \( q \) on \( \mathbb{R}^{n+1} \) so that:

(ii) \( g \) is homogeneous of degree \( m \);

(iii) The inverse Fourier transform \( \hat{g}(x, t) \) vanishes for \( t < 0 \).

Let \( U \) be an open subset of \( \mathbb{R}^n \). We define Volterra symbols and Volterra \( \Psi \) DOs on \( U \times \mathbb{R}^{n+1} \) as follows.

**Definition 3.3.** \( S^m_\Psi(U \times \mathbb{R}^{n+1}), m \in \mathbb{Z} \), consists in smooth functions \( q(x, \xi, \tau) \) on \( U \times \mathbb{R}^n \times \mathbb{R} \) with an asymptotic expansion \( q \sim \sum_{j \geq 0} q_{m-j} \)

where:

(i) \( q_0 \in C^\infty(U \times [(\mathbb{R}^n \times \mathbb{R})/0]) \) is a homogeneous Volterra symbol of degree \( l \), i.e. \( q_0 \) is parabolic homogeneous of degree \( l \) and satisfies the property (i) in **Lemma 2.3** with respect to the last \( n+1 \) variables;

(ii) The sign \( \sim \) means that, for any integer \( N \) and any compact \( K \), \( U \), there is a constant \( C_{N_Ka_b} > 0 \) such that for \( x \in K \) and for \( |\xi| + |\tau|^{\frac{1}{2}} > 1 \) we have

\[ |\partial^a_x \partial^b_\tau q_{m-j}(x, \xi, \tau)| \leq C_{N_Ka_b}(l|x| + |\tau|^{\frac{1}{2}})^{m-N-|b|-2k}. \] (3.9)

**Definition 3.4.** \( S^m_\Psi(U \times \mathbb{R}), m \in \mathbb{Z} \), consists in continuous operators \( Q_0 \) from \( C^\infty(U \times \mathbb{R}) \) to \( C^\infty(U \times \mathbb{R}) \) such that:

(i) \( Q_0 \) has the Volterra property;

(ii) \( Q_0 = q(x, D_x, D_t) + R \) for some symbol \( q \) in \( S^m_\Psi(U \times \mathbb{R}) \) and some smoothing operator \( R \).
In what follows, if $Q_0$ is a Volterra $\Psi DO$, we let $K_{Q_0}(x,y,t-s)$ denote its distribution kernel, so that the distribution $K_{Q_0}(x,y,t)$ vanishes for $t<0$.

**Definition 3.5.** Let $q_m(x,\xi,\tau) \in C^\infty(U \times (\mathbb{R}^{n+1}/0))$ be a homogeneous Volterra symbol of order $m$ and let $g_m \in C^\infty(U) \otimes S'(\mathbb{R}^{n+1})$ denote its unique homogeneous extension given by Lemma 2.3. Then:

(i) $\tilde{q}_m(x,y,t)$ is the inverse Fourier transform of $g_m(x,\xi,\tau)$ in the last $n+1$ variables;
(ii) $q_m(x,\xi,\tau)$ is the operator with kernel $q_m(x,y,t)$.

**Proposition 3.6.** ([5,13]) The following properties hold.

1) Composition. Let $Q_j \in \mathcal{P}_\nu^m(U \times \mathbb{R})$, $j=1,2$ have symbol $q_j$ and suppose that $Q_1$ or $Q_2$ is properly supported. Then $Q_1Q_2$ is a Volterra $\Psi DO$ of order $m_1+m_2$ with symbol $q_1 \circ q_2 \sim \sum \frac{1}{\alpha!} \tilde{q}_1^{\alpha} \tilde{q}_2^{\beta}$.

2) Parametrices. An operator $Q$ is the order $m$ Volterra $\Psi DO$ with the paramatrix $P$ then $QP = 1 - R_1$, $PQ = 1 - R_2$ (3.10)

where $R_1$, $R_2$ are smoothing operators.

**Proposition 3.7.** ([5,13]) The differential operator $\tilde{D}_E^2 + \partial_t$ is invertible and its inverse $(\tilde{D}_E^2 + \partial_t)^{-1}$ is a Volterra $\Psi DO$ of order $-2$.

We denote by $M^\phi$ the fixed-point set of $\phi$, and for $a = 0, \ldots, n$, we let $M^{\phi}_a = \bigcup_{a \leq r \leq n} M^{\phi}_r$, where $M^{\phi}_a$ is an $a$-dimensional submanifold. Given a fixed-point $x_0$ in a component $M^{\phi}_a$, consider some local coordinates $x = (x^1, \ldots, x^d)$ around $x_0$. Setting $b = n-a$, we may further assume that over the range of the domain of the local coordinates there is an orthonormal frame $e_1(x), \ldots, e_b(x)$ of $N^{\phi}_a$. This defines fiber coordinates $v = (v_1, \ldots, v_b)$. Composing with the map $(x,v) \in N^{\phi}(x_0) \rightarrow \exp(x)$ we then get local coordinates $x^1, \ldots, x^d, v^1, \ldots, v^b$ for $M$ near the fixed point $x_0$. We shall refer to this type of coordinates as *tubular coordinates*. Then $N^{\phi}(x_0)$ is homeomorphic to a tubular neighborhood of $M^\phi$. Set $i_{M^\phi} : M^\phi \hookrightarrow M$ be an inclusion map. Since $d\phi$ preserves $E$ and $E^\perp$, considering the oriented (local) orthonormal basis $(f_1, \ldots, f_k, h_1, \ldots, h_{n-k})$, set

$$d\phi_{x_0} = \begin{pmatrix} \exp(L_1) & 0 \\ 0 & \exp(L_2) \end{pmatrix},$$

where $L_1 \in \mathfrak{so}(k)$ and $L_2 \in \mathfrak{so}(n-k)$.

Let

$$\hat{A}(R^{M^\phi}) = \det \left( \begin{array}{c} R^{M^\phi}/4\pi \\ \sinh(R^{M^\phi}/4\pi) \end{array} \right); \quad \nu_{\phi}(R^{M^\phi}) := \det^{-\frac{1}{2}}(1 - \phi N e^{-\frac{R^{M^\phi}}{4\pi}}).$$

(3.12)

The aim of this section is to prove the following result.

**Theorem 3.8.** (Local Equivariant Sub-Signature Index Theorem. Even Dimension)

Let $x_0 \in M^\phi$, then

$$\lim_{t \to 0} \text{Str} \left[ \hat{\phi}(x_0)K_t(x_0,\phi(x_0)) \right] = \left( \frac{1}{\sqrt{-1}} \right)^k 2 \pi \left\{ \hat{A}(R^{M^\phi}) \nu_{\phi}(R^{M^\phi}) i_{M^\phi}^{\phi} \left[ \det^{\frac{1}{2}} \left( \cosh \left( \frac{R^E}{4\pi} - \frac{L_1}{2} \right) \right) \right] \right\} \left(\phi \right),$$

(3.13)

where $L_1 \in \mathfrak{so}(k), L_2 \in \mathfrak{so}(n-k)$ and $\text{Pf} \left( \frac{R^{E^\perp}}{4\pi} - \frac{L_2}{2} \right)$ denotes the Pfaffian of $\left( \frac{R^{E^\perp}}{4\pi} - \frac{L_2}{2} \right)$.

Next we give a detailed proof of Theorem 3.9. Let $Q = (\tilde{D}_E^2 + \partial_t)^{-1}$. For $x \in M^\phi$ and $t > 0$ set

$$I_Q(x,t) := \tilde{\phi}(x)^{-1} \int_{\phi^t(x)} \phi(x,v)K_Q(x,v,\exp_{\phi}(\phi(x)v))dv.$$

(3.14)

Here we use a trivialization over $\wedge(T^*M)$ about the tubular coordinates. Using the tubular coordinates, we have

$$I_Q(x,t) = \int_{|v|<\varepsilon} \tilde{\phi}(x,0)^{-1}\tilde{\phi}(x,v)K_Q(x,v,\phi(x)v)dv.$$

(3.15)
We define the Getzler order as follows:

\[ q_{m-j}^{(T^*M)}(x, v; \xi, \tau) := \tilde{\phi}(x, 0)^{-1} \tilde{\phi}(x, v)q_{m-j}(x, v; \xi, \tau). \]  

(3.16)

We mention the following result

**Proposition 3.9.** [19] Let \( Q \in \Psi_V^\alpha(M \times \mathbb{R}, \wedge (T^*M)), \ m \in \mathbb{Z}. \) Uniformly on each component \( M_0^\alpha \)

\[ I_Q(x, t) \sim \sum_{j \geq 0} t^{-\frac{(j+|\tau|)+1}{2j}} I_j^Q(x) \text{ as } t \to 0^+, \]

(3.17)

where \( I_j^Q(x) \) is defined by

\[ I_j^Q(x) := \sum_{|a| \leq m-|\tau|+2j} \int \frac{\nu^a}{a!} \left( \partial_a^q q_{j}^{(T^*M)} \right)^\vee \langle x, 0, (1 - \phi'(x))v, 1 \rangle dv. \]

(3.18)

Similar to Theorem 1.2 in [15] and Section 2 (d) in [8], we have

\[ \text{Str}_x [\phi(\exp(-tD_M^2))] = \langle \sqrt{-1} \rangle_{\mathbb{R}} \int_M \text{Str}_x [\tilde{c}(E, g_E)k_t(x, \phi(x))] \text{ dx} \]

\[ = \langle \sqrt{-1} \rangle_{\mathbb{R}} \int_M \text{Str}_x [\tilde{c}(E, g_E)K(D_M^2+\partial_t)^{-1}(x, \phi(x), t)] \text{ dx}. \]

(3.19)

We will compute the local index in this trivialization. Let \((V, q)\) be a finite dimensional real vector space equipped with a quadratic form. Let \( C(V, q) \) be the associated Clifford algebra, i.e., the associative algebra generated by \( V \) with the relations \( v \cdot w + w \cdot v = -2q(v, w) \) for \( v, w \in V \). Let \( \{e_1, \ldots, e_n\} \) be an orthonormal basis of \((V, q)\), let \((C(V, q) \otimes C(V, -q))\) be the grading tensor product of \((C(V, q))\) and \((C(V, -q))\), and \( \wedge^* V \otimes \wedge^* V \) be the grading tensor product of \( \wedge^* V \) and \( \wedge^* V \). Define the symbol map:

\[ \sigma : C(V, q) \otimes C(V, -q) \to \wedge^* V \otimes \wedge^* V; \]

(3.20)

where \( \sigma(c(e_{i_1}) \cdots c(e_{i_j}) \otimes 1) = e_{i_1} \wedge \cdots \wedge e_{i_j} \otimes 1, \sigma(1 \otimes \tilde{c}(e_{i_1}) \cdots \tilde{c}(e_{i_j})) = 1 \otimes \tilde{c}(e_{i_1}) \wedge \cdots \wedge \tilde{c}(e_{i_j}) \). Using the interior multiplication \( \iota(e_j) : \wedge^* V \to \wedge^{*+1} V \) and the exterior multiplication \( \epsilon(e_j) : \wedge^* V \to \wedge^{*-1} V \), we define representations of \((C(V, q))\) and \((C(V, -q))\) on the exterior algebra:

\[ c : C(V, q) \to \text{End } \wedge V, \ i \mapsto c(e_j) : \epsilon(e_j) - \iota(e_j); \]

(3.21)

\[ \tilde{c} : C(V, -q) \to \text{End } \wedge V, \ i \mapsto \tilde{c}(e_j) : \epsilon(e_j) + \iota(e_j). \]

(3.22)

The tensor product of these representations yields an isomorphism of superalgebras

\[ c \otimes \tilde{c} : C(V, q) \otimes C(V, -q) \to \text{End } \wedge V \]

(3.23)

which we will also denote by \( c \). We obtain a supertrace (i.e., a linear functional vanishing on supercommutators) on \((C(V, q) \otimes C(V, -q))\) by setting \( \text{Str}(a) = \text{Str}_{\text{End } \wedge V}(c(a)) \) for \( a \in C(V, q) \otimes C(V, -q) \), where \( \text{Str}_{\text{End } \wedge V} \) is the canonical supertrace on \( \text{End } V \).

**Lemma 3.10.** For \( 1 \leq i_1 < \cdots < i_p \leq n, \ 1 \leq j_1 < \cdots < j_q \leq n \), when \( p = q = n \),

\[ \text{Str}[c(e_{i_{i_1}}) \cdots c(e_{i_p}) \tilde{c}(e_{i_{j_1}}) \cdots \tilde{c}(e_{i_{j_q}})] = (-1)^{\frac{p+1}{2} n} 2^n \]

(3.24)

and otherwise equals zero.

We will also denote the volume element in \( \wedge V \otimes \wedge V \) by \( \omega = e_1 \wedge \cdots \wedge e^n \wedge \tilde{e}_1 \wedge \cdots \wedge \tilde{e}^n \). For \( a \in \wedge V \otimes \wedge V \), let \( Ta \) be the coefficient of \( \omega \). The linear functional \( T : \wedge V \otimes \wedge V \to \mathbb{R} \) is called the Berezin trace. Then for a \( a \in C(V, q) \otimes (V, q) \), we have \( \text{Str}(a) = (-1)^{\frac{p+1}{2} n} 2^n (T \sigma)(a) \).

We define the Getzler order as follows:

\[ \text{deg} \partial_t = \frac{1}{2} \text{deg} \partial_t = -\text{deg} x^t = 1, \ \text{deg} e_j = 1, \ \text{deg} \tilde{c}(e_j) = 0. \]

(3.25)

Let \( Q \in \Psi_V^\alpha(\mathbb{R}^n \times \mathbb{R}, \wedge^* T^* M) \) have symbol

\[ q(x, \xi, \tau) \sim \sum_{k \leq m} q_k(x, \xi, \tau), \]

(3.26)

where \( q_k(x, \xi, \tau) \) is an order \( k \) symbol. Then taking components in each subspace \( \wedge^j T^* M \otimes \wedge^j T^* M \) of \( \wedge^* T^* M \otimes \wedge^* T^* M \) and using Taylor expansions at \( x = 0 \) give formal expansions

\[ \sigma[q(x, \xi, \tau)] \sim \sum_{j,k} \sigma[q_k(x, \xi, \tau)]^{(j)} \sim \sum_{j,k} \sum_{\alpha \geq 0} \frac{x^\alpha}{\alpha!} \sigma[\partial_\alpha^q q_k(0, \xi, \tau)]^{(j)}. \]

(3.27)
The symbol $\sum_{\alpha \leq |a|} \sigma_{\alpha}(\partial_{\alpha} q_{k}(0, \xi, \tau))$ is the Getzler homogeneous of $k + j - |a|$. Therefore, we can expand $\sigma(q(x, \xi, \tau))$ as

$$\sigma(q(x, \xi, \tau)) \sim \sum_{j \geq 0} q_{(m-j)}(x, \xi, \tau), \quad q_{(m)} \neq 0, \quad (3.28)$$

where $q_{(m-j)}$ is a Getzler homogeneous symbol of degree $m - j$.

**Definition 3.11.** The integer $m$ is called as the Getzler order of $Q$. The symbol $q_{(m)}$ is the principal Getzler homogeneous symbol of $Q$. The operator $Q(m) = q_{(m)}(x, D_x, D_t)$ is called the model operator of $Q$.

Let $e_1, \ldots, e_n$ be an oriented orthonormal basis of $T_{x_0} \mathcal{M}$ such that $e_1, \ldots, e_a$ span $T_{x_0} \mathcal{M}^\phi$ and $e_{a+1}, \ldots, e_n$ span $N_{x_0}^\phi$. This provides us with normal coordinates $(x_1, \ldots, x_n) \mapsto \exp_{x_0}(x_1 e_1 + \cdots + x_n e_n)$. Moreover using parallel transport enables us to construct a synchronous local oriented tangent frame $e_1(x), \ldots, e_n(x)$ such that $e_1(x), \ldots, e_a(x)$ form an oriented frame of $T_{x_0} \mathcal{M}^\phi$ and $e_{a+1}(x), \ldots, e_n(x)$ form an (oriented) frame $N_{x_0}^\phi$ (when both frames are restricted to $\mathcal{M}^\phi$). This gives rise to trivializations of the tangent and exterior algebra bundles. Write

$$\phi'(0) = \begin{pmatrix} 1 & 0 \\ 0 & \phi_N \end{pmatrix} = \exp(A_{\phi}), \quad (3.29)$$

where $A_{\phi} \in \mathfrak{so}(n)$.

Let $\wedge(n) = \wedge^a \mathbb{R}^n$ be the exterior algebra of $\mathbb{R}^n$. We shall use the following gradings on $\wedge(n) \hat{\otimes} \wedge(n)$,

$$\wedge(n) \hat{\otimes} \wedge(n) = \bigoplus_{1 \leq k_1, k_2 \leq a} \wedge^{k_1} \hat{\otimes} \wedge^{k_2} \wedge(n), \quad (3.30)$$

where $\wedge^{k_2}(n)$ is the space of forms $dx^{k_1} \cdots dx^{k_2}$ with $1 \leq i_1 < \cdots < i_k \leq a$ and $a + 1 \leq \cdots < i_{k+1} \leq n$. Given a form $\omega \in \wedge(n) \hat{\otimes} \wedge(n)$, denote by $\omega(k_1, k_2)$ its component in $\wedge(n)(k_1) \hat{\otimes} \wedge(n)(k_2)$, where $\wedge(n)(k_1, k_2)$ is the component of $\omega$ in $\wedge^{k_1} \hat{\otimes} \wedge^{k_2} \wedge(n)$.

Let $A \in Cl(V, q) \hat{\otimes} Cl(V, -q)$, then

$$\text{Str}[\tilde{\phi} A] = \frac{1}{2} 2^n \left( \frac{1}{4} \det(1 - \phi N) \right) \sigma(A) |(0, a)(a, 0)|$$

$$+ (-1)^{a} 2^n \sum_{0 \leq k_1 \leq b, 0 \leq k_2 \leq b} \sigma(\tilde{\phi}) |(k_1, l_1)(a, k_2, l_2)| \sigma(A) |(a, b-l_1)(a, b-l_2)| |(n, n)|. \quad (3.31)$$

In order to calculate $\text{Str}[\tilde{\phi} A]$, we need to consider the representation of $|\sigma(\tilde{\phi})|(0, b)(0, l_2)(a, 0)(a, b-l_2)| |(n, n)$. Let the matrix $\phi N$ equal

$$\phi N = \begin{pmatrix} A_{\phi}^{k_1} + 1 & \cdots & 0 \\ & \ddots & \vdots \\ 0 & \cdots & A_{\phi}^{k_2} \end{pmatrix}, \quad A_{\phi}^{k_1} = \begin{pmatrix} \cos \theta_{k_1}^{j+1} & \sin \theta_{k_1}^{j+1} \\ -\sin \theta_{k_1}^{j+1} & \cos \theta_{k_1}^{j+1} \end{pmatrix}, \quad A_{\phi}^{k_2} = \begin{pmatrix} \cos \theta_{k_2}^{j+1} & \sin \theta_{k_2}^{j+1} \\ -\sin \theta_{k_2}^{j+1} & \cos \theta_{k_2}^{j+1} \end{pmatrix}. \quad (3.32)$$

From Lemma 3.2 in [26], then

**Lemma 3.12.** We have

$$\tilde{\phi} = \left( \frac{1}{2} \right)^{\frac{a+1}{2}} \prod_{j=\frac{a+1}{2}}^{n} \left( 1 + \cos \theta_j - (1 - \cos \theta_j) c(e_{2j-1}) c(e_{2j}) c(e_{2j-1}) \tilde{c}(e_{2j}) \right) + \sin \theta_j \left( c(e_{2j-1}) c(e_{2j}) - c(e_{2j-1}) \tilde{c}(e_{2j}) \right). \quad (3.33)$$

Then we obtain

$$\sigma(\tilde{\phi}) |(0, b)(0, l_2)| = \left( \frac{1}{2} \right)^{\frac{a+1}{2}} \prod_{j=\frac{a+1}{2}}^{n} \left( (1 - \cos \theta_j) c(e_{2j-1}) c(e_{2j}) c(e_{2j-1}) \tilde{c}(e_{2j}) + \sin \theta_j \left( c(e_{2j-1}) c(e_{2j}) \right) \right)$$

$$= \left( \frac{1}{2} \right)^{\frac{a+1}{2}} \prod_{j=\frac{a+1}{2}}^{n} \left( (1 - \cos \theta_j) c(e_{2j-1}) c(e_{2j}) + \sin \theta_j \right). \quad (0, l_2)$$
and

\[ \sigma_8 K. Bao et al. / Journal of Nonlinear Mathematical Physics. In Press \]

By (2.19), let \( Q \)

\[ \text{Similar to Lemma 2.9 in [19], we get} \]

\[ \text{Let} \quad Q = \tilde{Q}(c_1) \text{and} \quad Q = \tilde{Q}(c_2) \text{.} \]

\[ \text{Let} \quad Q = \tilde{Q}(c_3) \text{.} \]

Next we calculate \( |\sigma(A)|^{(a,0,\alpha,b-1)} \). In the following, we shall use the following “curvature forms”:

\[ \begin{align*}
R' &= (R_{ij})_{1 \leq i,j \leq a}, \quad R'' = (R_{ab+1})_{1 \leq i,j \leq b} \text{. Let}
\end{align*} \]

\[ \begin{align*}
\dot{R} &= \frac{1}{4} \sum_{1 \leq i,j,k \leq n} (R^F_{ij} f_{i\beta} \hat{c}(f_{i\alpha}) \hat{c}(f_{\beta})), \\
\ddot{R} &= \frac{1}{4} \sum_{1 \leq i,j,k \leq n} (R^E_{ij} f_{i\alpha} \hat{c}(f_{j\alpha}) \hat{c}(f_{j\beta})), \\
\dddot{R} &= \frac{1}{4} \sum_{1 \leq i,j,k \leq n} ((R^{E'}_{ij} - L_1) f_{i\alpha} \hat{c}(f_{j\alpha}) \hat{c}(f_{j\beta})), \\
\end{align*} \]

By (2.19), let \( F = \tilde{D}_E^2 \), we get

Proposition 3.13. The model operator of \( F \) is

\[ F_{(2)} = -\sum_{r=1}^{n} \left( \partial_r + \frac{1}{8} \sum_{1 \leq i,j \leq n} (R^{TM}(e_i,e_j)e_i,e_i) y_i e_i + e_i \right)^2 + \frac{1}{8} \sum_{1 \leq i,j \leq n} \sum_{1 \leq i,j \leq n} (R^F(e_i,e_j,f_{i\alpha}f_{i\beta}) \hat{e}(f_{i\alpha}) \hat{e}(f_{i\beta}) + \frac{1}{8} \sum_{1 \leq i,j \leq n} \sum_{1 \leq i,j \leq n} (R^E(e_i,e_j,h_{i\alpha},h_{i\beta}) e_i + e_i \hat{e}(h_{i\alpha}) \hat{e}(h_{i\beta})). \]

(3.34)

From the representation of \( F_{(2)} \), we get the model operator of \( \frac{\partial}{\partial t} + \tilde{D}_E^2 \) is \( \frac{\partial}{\partial t} + F_{(2)} \). And we have

\[ \left( \frac{\partial}{\partial t} + F_{(2)} \right) K_{Q_{(2)}}(x,y,t) = 0. \]

(3.35)

Similar to Lemma 2.9 in [19], we get

Lemma 3.14. Let \( Q \in \Psi^{(2)}(\mathbb{R}^n \times \mathbb{R}, \wedge (T^* M)) \) be a parametrix for \( (F_{(2)} + \partial_t)^{-1} \). Then

(1) \( Q \) has Getzler order \(-2\) and its model operator is \( (F_{(2)} + \partial_t)^{-1} \).

(2) For all \( t > 0 \),

\[ \left( \sqrt{-1} \right)^{\frac{1}{2}} \hat{c}(E, g^F) \hat{c}(E, g^F) \right)^{4 \pi t} \frac{(4 \pi t)^{-\frac{1}{2}}} {\sin^2 \left( \frac{1}{2} \right)} \det^2 \left( \frac{\partial}{\partial t} + F_{(2)} \right) \det^{-\frac{1}{2}} (1 - \phi^N e^{-iR}) \exp \left( t(\tilde{R} + \tilde{R}) \right). \]

(3.37)

Similar to Lemma 3.6 in [22], we have

Lemma 3.15. \( Q \in \Psi^{(2)}(\mathbb{R}^n \times \mathbb{R}, \wedge (T^* M)) \) has the Getzler order \( m \) and model operator \( Q_{(m)} \). Then as \( \tau \rightarrow 0^+ \)

(1) \( \sigma [I_Q(0,t)]^{(j)} = O(t^{j-m-\frac{1}{2}}), \) if \( m - j \) is odd.

(2) \( \sigma [I_Q(0,t)]^{(j)} = O(t^{j-m-\frac{1}{2}})Q_{(m)}(0,1)^{(j)} + O(t^{j-m-\frac{1}{2}}), \) if \( m - j \) is even.
In particular, for \( m = -2 \) and \( j = a \) and \( a \) is even we get
\[
\sigma [I_Q(0, t)]^{(n, (a, b - l))} = I_{Q(-2)}(0, 1)^{(a, (a, b - l))} + O(t^\frac{1}{2}).
\] (3.38)

With all these preparations, we are going to prove the local even dimensional equivariant index theorem for sub-signature operators. Substituting (3.34), (3.37) into (3.31), we obtain
\[
\lim_{t \to 0} \text{Str}_\tau \left[ \tilde{\phi}(x_0)(\sqrt{-1})^{\frac{n}{2}} \tilde{c}(E, g_E^\tau) I_{(F^{+h})^{-1}}(x_0, t) \right] = (-1)^{-2n}(\frac{1}{2})^{\frac{n}{2}} (4\pi)^{-\frac{n}{2}}(\sqrt{-1})^{\frac{n}{2}} |A(R^{g_E}) v_\phi (R^{g_E}) \sigma \left[ \tilde{c}(f_1) \cdots \tilde{c}(f_k) \exp(\tilde{R} + \tilde{R}) \right] |^{(n, a, b)}.
\]

Lemma 3.16. Let \( L_1 \in so(k) \), \( L_2 \in so(n - k) \), we have
\[
\left| \sigma \left[ \tilde{c}(f_1) \cdots \tilde{c}(f_k) \exp(\tilde{R} + \tilde{R}) \right] \right|^{(n)} = (-1)^{-\frac{k}{2}} \det^\frac{1}{2} \left( \cosh \left( \frac{RE}{4\pi} - \frac{L_1}{2} \right) \right)
\times \det^\frac{1}{2} \left( \sinh \left( \frac{RE- L_2}{2} \right) \right)
\times \text{Pf} \left( \frac{RE - L_2}{2} \right).
\] (3.40)

Proof. In order to compute this differential form, we make use of the Chern root algorithm (see [22]). Assume that \( n = \dim M \) and \( k = \dim E \) are both even integers. As in [7], let \( L_1 \in so(k), L_2 \in so(n - k) \), we write
\[
RE - L_1 = \begin{pmatrix}
0 & -\theta_1 & 0 & 0 \\
\theta_1 & 0 & & \\
& \ddots & \ddots & 0 \\
0 & & & \theta_{k/2} & 0
\end{pmatrix},
RE - L_2 = \begin{pmatrix}
0 & -\hat{\theta}_1 & 0 & 0 \\
\hat{\theta}_1 & 0 & & \\
& \ddots & \ddots & 0 \\
0 & & & \hat{\theta}_{k/2} & 0
\end{pmatrix}.
\] (3.41)

Then we obtain
\[
\frac{1}{4} \sum_{1 \leq \alpha, \beta \leq k} \langle (RE - L_1) f_{\alpha} f_{\beta} \hat{c}(f_{\alpha}) \hat{c}(f_{\beta}) \rangle = \frac{1}{2} \sum_{1 \leq \alpha < \beta \leq k} \langle (RE - L_1) f_{\alpha} f_{\beta} \hat{c}(f_{\alpha}) \hat{c}(f_{\beta}) \rangle
= \frac{1}{2} \sum_{1 \leq \beta \leq k} \theta_{\hat{\alpha}} \hat{c}(f_{\beta - 1}) \hat{c}(f_{\beta});
\] (3.42)
\[
\frac{1}{4} \sum_{1 \leq \alpha, \beta \leq n-k} \langle (RE - L_2) h_{\alpha} h_{\beta} \hat{c}(h_{\alpha}) \hat{c}(h_{\beta}) \rangle = \frac{1}{2} \sum_{1 \leq \alpha < \beta \leq n-k} \langle (RE - L_2) h_{\alpha} h_{\beta} \hat{c}(h_{\alpha}) \hat{c}(h_{\beta}) \rangle
= \frac{1}{2} \sum_{1 \leq \beta \leq \frac{n-k}{2}} \hat{\theta}_{\beta} \hat{c}(h_{2\beta - 1}) \hat{c}(h_{2\beta});
\] (3.43)

Then the left hand side of (3.40) is
\[
\left| \sigma \left[ \tilde{c}(f_1) \cdots \tilde{c}(f_k) \exp(\tilde{R} + \tilde{R}) \right] \right|^{(n)}
= \left| \sigma \left( \tilde{c}(f_1) \cdots \tilde{c}(f_k) \prod_{1 \leq j \leq \frac{k}{2}} \exp \left( \frac{1}{2} \theta_j \hat{c}(f_{2j-1}) \hat{c}(f_{2j}) \right) \right) \prod_{1 \leq j \leq \frac{n-k}{2}} \exp \left( \frac{1}{2} \hat{\theta}_{j} \hat{c}(h_{2j-1}) \hat{c}(h_{2j}) \right) \right|^{(n)}.
\]
The purpose of this section is to compute
\[\widetilde{\operatorname{ind}}(\tilde{E},g^F) = \mathrm{Tr}(\tilde{E},g^F)_{\ker \tilde{D}_E^\perp} - \mathrm{Tr}(\tilde{E},g^F)_{\ker \tilde{D}_E^\perp} \]

Now we consider the right hand side of (3.40),
\[(R^E - L_1)^{2p} = (-1)^p\begin{pmatrix} \theta_1^{2p} & 0 & 0 & \cdots \\ 0 & \theta_1^{2p} & 0 & \cdots \\ 0 & 0 & \theta_1^{2p} & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{pmatrix}. \tag{3.45}\]

Then
\[
\det \left( \cosh \left( \frac{R^E - L_1}{2} \right) \right) = \prod_{j=1}^{\frac{1}{2}} \left( \sum_{p=0}^{\infty} \frac{(\theta_1/2)^{2p}}{(2p)!} \right) = \prod_{j=1}^{\frac{1}{2}} \cosh \left( \frac{\theta_1}{2} \right) = \prod_{j=1}^{\frac{1}{2}} e^{\frac{\theta_1}{2}} + e^{-\frac{\theta_1}{2}} = \prod_{j=1}^{\frac{1}{2}} \cosh \frac{\theta_1}{2}. \tag{3.46}\]

Similarly, we have
\[
\det \left( \sinh \left( \frac{R^E - L_2}{2} \right) \right) = \prod_{j=1}^{\frac{1}{2}} \sin \left( \frac{\theta_j}{2} \right). \tag{3.47}\]

On the other hand,
\[
Pf \left( \frac{R^E - L_2}{2} \right) = T \left( \exp \left( \sum_{j=1}^{\infty} \frac{\theta_j}{2} h_j h^j \right) \right) = T \left( \exp \left( \sum_{1 \leq j \leq \frac{1}{2}} \frac{\theta_j}{2} h_j^{j} \right) \right) = \prod_{j=1}^{\frac{1}{2}} \frac{\theta_j}{2}. \tag{3.48}\]

Combining these equations, the proof of lemma 3.17 is complete. \(\square\)

### 3.2. The Local Odd Dimensional Equivariant Index Theorem for Sub-Signature Operators

In this section, we give a proof of a local odd dimensional equivariant index theorem for sub-signature operators. Let \(M\) be an odd dimensional oriented closed Riemannian manifold. Using (2.19) in Section 2, we may define the sub-signature operators \(\tilde{D}_E\). Let \(\gamma\) be an orientation reversing involution isometric acting on \(M\). Let \(\gamma\) preserve \(E, E^\perp\) and preserve the orientation of \(E\), then \(\tilde{\gamma}(E, g^E) = \tilde{\gamma}(E, g^E)\tilde{\gamma}\), where \(\tilde{\gamma}\) is the lift on the exterior algebra bundle \(\wedge T^*M\) of \(d\gamma\). There exists a self-adjoint lift \(\tilde{\gamma} : \Gamma(M; \wedge (T^*M)) \to \Gamma(M; \wedge (T^*M))\) of \(d\gamma\) satisfying
\[
\tilde{\gamma}^2 = 1; \quad \tilde{D}_E \tilde{\gamma} = -\tilde{\gamma} \tilde{D}_E. \tag{3.49}\]

Now the \(+1\) and \(-1\) eigenspaces of \(\tilde{\gamma}\) give a splitting
\[
\Gamma(M; \wedge (T^*M)) \cong (\Gamma^+(M; \wedge (T^*M)) \oplus \Gamma^-(M; \wedge (T^*M))) \tag{3.50}\]
then the sub-signature operator interchanges \(\Gamma^+(M; \wedge (T^*M))\) and \(\Gamma^-(M; \wedge (T^*M))\), and \(\tilde{\gamma}(E, g^E)\) preserves \(\Gamma^+(M; \wedge (T^*M))\) and \(\Gamma^-(M; \wedge (T^*M))\).

Denotes by \(\tilde{D}_E^\perp\) the restriction of \(\tilde{D}_E\) to \(\Gamma^+(M; \wedge (T^*M))\). We assume \(\dim E = k\) is even, then \((\tilde{D}_E)\tilde{\gamma}(E, g^E) = \tilde{\gamma}(E, g^E)(\tilde{D}_E)\) and \(\tilde{\gamma}(E, g^E)\) is a linear map from \(\ker \tilde{D}_E\) to \(\ker \tilde{D}_E^\perp\).

The purpose of this section is to compute
\[
\widetilde{\operatorname{ind}}(\tilde{E},g^F) = \mathrm{Tr}(\tilde{E},g^F)_{\ker \tilde{D}_E^\perp} - \mathrm{Tr}(\tilde{E},g^F)_{\ker \tilde{D}_E^\perp}. \tag{3.51}\]
By the Mckean-Singer formula, we have

\[
\text{ind}_{c(E,g^E)}\left(\hat{D}_E^+\right) = \int_M (\sqrt{-1})^{\frac{d}{2}} \text{Tr}[\hat{\gamma}(E, g^E)K_0(x, \gamma(x))]dx \\
= \int_M (\sqrt{-1})^{\frac{d}{2}} \text{Tr}[\hat{\gamma}(E, g^E)K_{(F+\hat{h})^{-1}}(x, \gamma(x), t)]dx.
\] (3.52)

Let

\[
R^E - L_1 = \begin{pmatrix}
0 & -\theta_1 \\
\theta_1 & 0 \\
& \ddots \\
0 & -\theta_{\frac{d-1}{2}} & 0
\end{pmatrix}, \quad R_{\perp}^E - L_2 = \begin{pmatrix}
0 & -\hat{\theta}_1 \\
\hat{\theta}_1 & 0 \\
& \ddots \\
0 & -\hat{\theta}_{\frac{d-1}{2}} & 0
\end{pmatrix};
\] (3.53)

and

\[
\text{Pf}\left(\frac{R_{\perp}^E - L_2}{2}\right) = \prod_{j=1}^{n-k-1} \hat{\theta}_j^2.
\] (3.54)

Similar to Theorem 3.9, we get the main Theorem in this section.

**Theorem 3.17.** *(Local odd dimensional equivariant index Theorem for sub-signature operators)*

Let \(x_0 \in M^n\), then

\[
\lim_{t \to 0} \text{Tr} \left[\hat{\gamma}(x_0)\hat{\gamma}^E k_{(F+\hat{h})^{-1}}(x_0, t)\right] = -\left(\frac{1}{\sqrt{-1}}\right)^{\frac{d-1}{2}} 2^\frac{d-1}{2} \left[\hat{\Lambda}(R^M)^v \hat{\Lambda}(R^{\perp})\right]_{M^2}^{\nu_\phi} \left[\text{det}^{\frac{1}{2}} \left(\frac{\cosh (\frac{R^E}{4\pi} - \frac{L_1}{2})}{\frac{R_{\perp}^E}{4\pi} - \frac{L_2}{2}}\right)\right]^{(a,0)}(x_0). (3.55)
\]

**CONFLICTS OF INTEREST**

The authors declare they have no conflicts of interest.

**AUTHORS' CONTRIBUTION**

KB and YW contributed in study conceptualization and writing (review and editing) the manuscript. JW and YW contributed in data curation, formal analysis and writing (original draft). YW contributed in funding acquisition and project administration, supervised the project, formal analysis and writing (original draft) the manuscript.

**FUNDING**

This research was funded by National Natural Science Foundation of China: No. 11771070. NSFC. 11901322

**ACKNOWLEDGMENTS**

The work of the first author was supported by NSFC. 11901322. The work of the third author was supported by NSFC. 11771070. The authors also thank the referees for their careful reading and helpful comments.

**REFERENCES**