Zeitschrift: L'Enseignement Mathématique

Herausgeber: Commission Internationale de l'Enseignement Mathématique

Band: 48 (2002)

Heft: 1-2: L'ENSEIGNEMENT MATHÉMATIQUE

Artikel: TRIPLE RATIO ON THE UNITARY STIEFEL MANIFOLD

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Kapitel: 3. Orbits for the GL_q-action on $\tilde{T}_q$

DOI: https://doi.org/10.5169/seals-66067

3. ORBITS FOR THE GL_q-ACTION ON $\widetilde{T}_q$

Any $z \in \mathrm{Mat}(q \times q, \mathbf{C})$ can be written in a unique way as $z = x + iy$, with $x, y \in H_q$. We will be concerned with the set $\widetilde{T}_q$ defined by

(16) $\widetilde{T}_q = \{z \in \mathrm{Mat}(q \times q, \mathbf{C}) \mid z = x + iy,\ x \in H_q,\ y \in \overline{\Omega}_q,\ \det z \neq 0\}$.

Its interior is the classical *tube domain* over the cone Ω_q, namely

$$T_q = \{z \in \mathrm{Mat}(q \times q, \mathbf{C}) \mid z = x + iy,\ y \in \Omega_q\}.$$

Let $G = \mathrm{GL}(q, \mathbf{C})$ act on $\mathrm{Mat}(q \times q, \mathbf{C})$ by

(17) $$(g, z) \longmapsto gzg^*.$$

The spaces $H_q, \Omega_q, \overline{\Omega}_q$ are stable under this action, and hence $\widetilde{T}_q$ and T_q are invariant subsets under this action. We investigate the orbits and describe a full set of invariants for this action.

There is a natural invariant associated to a $\mathrm{GL}(q, \mathbf{C})$-orbit. To any $z \in \widetilde{T}_q$, we associate its *angular matrix* defined by

(18) $$a = a(z) = {z^*}^{-1} z.$$

Then the matrix associated to gzg^* is ${g^*}^{-1} a g^*$, so that the angular matrix $a(z)$ belongs to the same conjugacy class when z runs through a $\mathrm{GL}(q, \mathbf{C})$-orbit. As we shall see (Theorem 3.3 and Theorem 3.13), this invariant is close to characterizing the orbits.

Let us first prove some elementary properties of the angular matrix.

PROPOSITION 3.1. *Let $z = x + iy \in \widetilde{T}_q$, and let $a = {z^*}^{-1} z$ be its angular matrix. Then*

(i) $\mathrm{Sp}(a) \subset \mathrm{U}_1 = \{\mu \in \mathbf{C}, |\mu| = 1\}$;

(ii) *if* $1 \in \mathrm{Sp}(a)$, *then* y *is degenerate and*

$$\{v \in \mathbf{C}^q \mid av = v\} = \{v \in \mathbf{C}^q \mid yv = 0\}.$$

Proof. Let μ be an eigenvalue of a, and let $v \neq 0$ be an eigenvector for the eigenvalue μ. Then $zv = \mu z^* v$, and hence

$$(zv, v) = \mu(z^* v, v) = \mu(v, zv) = \mu\,\overline{(zv, v)}.$$

If $(zv, v) \neq 0$, then $|\mu| = 1$. So we now assume $(zv, v) = 0$. This amounts to $(xv, v) + i(yv, v) = 0$, so that in particular $(yv, v) = 0$. Now recall that y is positive semi-definite. So the condition $(yv, v) = 0$ implies that $yv = 0$. From this it follows that $zv = xv = z^* v$, and as z is assumed to be invertible, this implies $\mu = 1$. This shows (i) and part of (ii). Conversely, the condition $yv = 0$ implies trivially $av = v$. $\square$

In particular, we may consider the polynomial $d(\mu) = \det(z - \mu z^*)$. The roots of d are the eigenvalues of the angular matrix. The set of these roots, counted with their multiplicities, will be called the *angular spectrum* of z.

We first consider the case of T_q. So let $z = x + iy \in T_q$. Then as y is positive-definite, we may define its square root $y^{1/2}$ as the unique positive-definite Hermitian matrix whose square is y. Then we may write

$$x + iy = y^{\frac{1}{2}}(y^{-\frac{1}{2}}xy^{-\frac{1}{2}} + i1_q)y^{\frac{1}{2}}\,.$$

This shows that any $\mathrm{GL}(q,\mathbf{C})$-orbit contains some element of the form $x+i1_q$, where $x \in H_q$. But by the classical diagonalization theorem for Hermitian forms, there exists an orthonormal basis in which the Hermitian form associated to x is diagonal. In other words, there exists a unitary matrix u and real numbers $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_q$ such that

$$uxu^* = \Lambda = \begin{pmatrix} \lambda_1 & & & \\ & \lambda_2 & & \\ & & \ddots & \\ & & & \lambda_q \end{pmatrix}.$$

Moreover, if Λ and Λ' are two such diagonal matrices, then $\Lambda + i\mathbf{1}_q$ and $\Lambda' + i\mathbf{1}_q$ are not conjugate under the action of $\mathrm{GL}(q,\mathbf{C})$ unless $\Lambda = \Lambda'$. Hence we have shown the following result, which of course is the well-known fact that there is a simultaneous diagonalization for two Hermitian forms if one of them is positive-definite.

THEOREM 3.2. *The set of matrices of the form*

$$\Lambda = \begin{pmatrix} \lambda_1 + i & & & \\ & \lambda_2 + i & & \\ & & \ddots & \\ & & & \lambda_q + i \end{pmatrix} \tag{19}$$

with $\lambda_1 \geq \lambda_2 \cdots \geq \lambda_q$ *is a full set of representatives of the* $\mathrm{GL}(q,\mathbf{C})$*-orbits in* T_q.

The angular matrix associated to Λ is

$$\begin{pmatrix} \frac{\lambda_1+i}{\lambda_1-i} & & & \\ & \frac{\lambda_2+i}{\lambda_2-i} & & \\ & & \ddots & \\ & & & \frac{\lambda_q+i}{\lambda_q-i} \end{pmatrix}. \tag{20}$$

The latter is a semi-simple matrix with spectral values

$$\mu_j = \frac{\lambda_j + i}{\lambda_j - i}$$

for $1 \leq j \leq q$. Observe that these spectral values are complex numbers of modulus 1, but always different from 1. From the u_j we may recover the λ_j by the formula

$$\lambda_j = i\,\frac{1+\mu_j}{1-\mu_j}\,.$$

From these observations we get the following result.

THEOREM 3.3. *Two elements z and z' of T_q belong to the same* $\mathrm{GL}(q, \mathbf{C})$*-orbit if and only if their angular matrices are conjugate. The angular spectrum is a full set of invariants for the action of* $\mathrm{GL}(q, \mathbf{C})$ *on* T_q.

The situation for $\widetilde{T}_q$ is more complicated. In fact we may consider the extreme case where $y = 0$. Then x corresponds to a non-degenerate Hermitian form, and the orbit picture is given by the signature. So we need to consider matrices of the form

$$\Upsilon = \Upsilon_{n_+, n_-} = \begin{pmatrix} 1 & & & & & \\ & \ddots & & & & \\ & & 1 & & & \\ & & & -1 & & \\ & & & & \ddots & \\ & & & & & -1 \end{pmatrix}$$

with n_+ diagonal entries equal to $+1$ and n_- diagonal entries equal to -1, n_+ and n_- being arbitrary nonnegative integers such that $n_+ + n_- = q$. The corresponding angular matrix is the identity matrix $\mathbf{1}_q$.

Another source of difficulty comes from the fact that it is not always possible to find a basis in which both Hermitian forms associated to x and y are diagonal. For instance if $q = 2$, consider the matrix

$$z = \begin{pmatrix} i & \frac{i}{2} \\ -\frac{i}{2} & 0 \end{pmatrix} = \begin{pmatrix} 0 & \frac{i}{2} \\ -\frac{i}{2} & 0 \end{pmatrix} + i \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}.$$

Notice that its angular matrix is

$$a = \begin{pmatrix} 1 & 0 \\ 1 & 1 \end{pmatrix},$$

which is not semisimple.

From these examples we see that neither the angular spectrum of z nor the conjugacy class of the angular matrix characterizes the orbit of z.

Let n_1, n_2, n_3, n_4 be four nonnegative integers such that $n_1+2n_2+n_3+n_4 = q$, and let $\lambda_1, \lambda_2, \dots, \lambda_{n_1}$ be n_1 real numbers satisfying the condition

$$\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_{n_1} .$$

To such data we associate the matrix $\Lambda = \Lambda(\lambda_1, \lambda_2, \dots, \lambda_{n_1}, n_2, n_3, n_4)$ given by

$$(21) \qquad \begin{pmatrix} \lambda_1+i &&&&&&&&&&&& \\ & \ddots &&&&&&&&&&& \\ && \lambda_{n_1}+i &&&&&&&&&& \\ &&& i & 1 &&&&&&&& \\ &&& 1 & 0 &&&&&&&& \\ &&&&& \ddots &&&&&&& \\ &&&&&& i & 1 &&&&& \\ &&&&&& 1 & 0 &&&&& \\ &&&&&&&& 1 &&&& \\ &&&&&&&&& \ddots &&& \\ &&&&&&&&&& 1 && \\ &&&&&&&&&&& -1 & \\ &&&&&&&&&&&& \ddots \\ &&&&&&&&&&&&& -1 \end{pmatrix}$$

where there are n_2 diagonal 2×2 submatrices of the form $\begin{pmatrix} i & 1 \\ 1 & 0 \end{pmatrix}$, n_3 diagonal terms equal to 1 and n_4 diagonal terms equal to -1.

THEOREM 3.4. *Any* $\mathrm{GL}(q, \mathbf{C})$ *orbit in* $\widetilde{T}_q$ *contains one and only one matrix of the form* $\Lambda(\lambda_1, \lambda_2, \dots, \lambda_{n_1}, n_2, n_3, n_4)$.

Before beginning the proof, let us prove a couple of lemmas. Lemmas 3.6 and 3.7 are related to the classical Gauss's algorithm for diagonalizing an Hermitian form. Let r, s, n be three nonnegative integers such that $r+s=n$.

LEMMA 3.5. *The stabilizer in* $\mathrm{GL}(n, \mathbf{C})$ *of the matrix* $y_r = \begin{pmatrix} \mathbf{1}_r & \\ & \mathbf{0}_s \end{pmatrix}$ *is the subgroup*

$$(22) \qquad G_r = \left\{ \begin{pmatrix} u & v \\ 0 & h \end{pmatrix} \right\}$$

where $u \in \mathrm{U}(r)$, $v \in \mathrm{Mat}(r, s)$, $h \in \mathrm{GL}(s, \mathbf{C})$.

Proof. Easy computation.

Now we study the action of G_r in H_n. If $x \in H_n$, let us write

$$x = \begin{pmatrix} \alpha & b \\ b^* & \gamma \end{pmatrix}$$

where $\alpha \in H_r, b \in \mathrm{Mat}(r \times s, \mathbf{C})$ and $\gamma \in H_s$. If $g = \begin{pmatrix} u & v \\ 0 & h \end{pmatrix} \in G_r$, then $gxg^* = \begin{pmatrix} \alpha' & b' \\ b'^* & \gamma' \end{pmatrix}$, with

$$\alpha' = u\alpha u^* + ubv^* + vb^*u^* + v\gamma v^*$$
$$b' = ubh^* + v\gamma h^*$$
$$\gamma' = h\gamma h^* .$$

LEMMA 3.6. *Let* $x = \begin{pmatrix} \alpha & b \\ b^* & \gamma \end{pmatrix} \in H_n$, *with* $\alpha \in H_r$, $b \in \mathrm{Mat}(r \times s, \mathbf{C})$ *and* $\gamma \in H_s$. *Assume* $\det \gamma \neq 0$. *Then the orbit of* x *under* G_r *contains a matrix of the form* $\begin{pmatrix} \alpha' & 0 \\ 0 & \gamma \end{pmatrix}$ *with* $\alpha' \in H_r$.

Proof. This is a consequence of the previous formula with $u = \mathbf{1}_r$, $v = -b\gamma^{-1}$ and $h = \mathbf{1}_s$.

LEMMA 3.7. *Let* $x = \begin{pmatrix} \alpha & b \\ b^* & 0 \end{pmatrix} \in H_n$, *with* $\mathrm{rank}\, b = s$ *(so in particular* $r \geq s$*). Then the orbit of* x *under* G_r *contains an element of the form*

$$\begin{pmatrix} \beta & 0 & 0 \\ 0 & 0 & \mathbf{1}_s \\ 0 & \mathbf{1}_s & 0 \end{pmatrix}$$

with $\beta \in H_{r-s}$.

Proof. Consider the subgroup $\left\{ \begin{pmatrix} u & 0 \\ 0 & h \end{pmatrix}, \ u \in \mathrm{U}(r), \ h \in \mathrm{GL}_s(\mathbf{C}) \right\}$. It acts on the component b by $b' = ubh^*$. As $\mathrm{rank}(b) = s$, we may think of b as a set of s independent vectors in $\mathbf{C}^r$. By the Gram-Schmidt process, it is possible to find $h \in \mathrm{GL}_s(\mathbf{C})$ such that bh^* is a s-orthonormal frame in $\mathbf{C}^r$. But now two such frames are conjugate by the (left) action of $\mathrm{U}(r)$. Hence there exists $u \in \mathrm{U}(r)$ such that

$$ubh^* = \begin{pmatrix} 0 \\ \mathbf{1}_s \end{pmatrix} .$$

The matrix x we started with is conjugate under G_r to a matrix of the form

$$\begin{pmatrix} \alpha' & c & 0 \\ c^* & \beta & \mathbf{1}_s \\ 0 & \mathbf{1}_s & 0 \end{pmatrix}$$

where $\alpha' \in H_{r-s}$, $\beta \in H_s$ and $c \in \mathrm{Mat}((r-s)\times s, \mathbf{C})$. Now we use the action of the element

$$g = \begin{pmatrix} \mathbf{1}_{r-s} & 0 & -c \\ 0 & \mathbf{1}_s & -\frac{\beta}{2} \\ 0 & 0 & \mathbf{1}_s \end{pmatrix} \in G_r$$

to get the result. □

We are now ready to start the proof of Theorem 3.4.

STEP 1. Let $z = x + iy \in \widetilde{T}_q$. As y is positive semidefinite, there exists an element $g \in \mathrm{GL}(q, \mathbf{C})$ such that

$$gyg^* = \begin{pmatrix} 1 & & & & & \\ & \ddots & & & & \\ & & 1 & & & \\ & & & 0 & & \\ & & & & \ddots & \\ & & & & & 0 \end{pmatrix},$$

with r diagonal entries equal to 1, and s diagonal entries equal to 0, r and s being nonnegative integers satisfying $r + s = q$. In other terms, any $\mathrm{GL}(q, \mathbf{C})$-orbit in $\widetilde{T}_q$ contains an element of the form

$$\begin{pmatrix} \alpha + i\mathbf{1}_r & b \\ b^* & \gamma \end{pmatrix}$$

with $\alpha \in H_r, \gamma \in H_s, b \in \mathrm{Mat}(r \times s, \mathbf{C})$.

STEP 2. Now assume x is of the form

$$x = \begin{pmatrix} \alpha + i\mathbf{1}_r & b \\ b^* & \gamma \end{pmatrix}.$$

Consider γ. It is an Hermitian matrix of size s, and under the action of $\mathrm{GL}(s, \mathbf{C})$ it can be transformed to

$$\begin{pmatrix} \mathbf{0}_{n_2} & 0 & 0 \\ 0 & \mathbf{1}_{n_3} & 0 \\ 0 & 0 & -\mathbf{1}_{n_4} \end{pmatrix}$$

where $n_2 + n_3 + n_4 = s$. Hence x is conjugate under the action of G_r to an element of the form

$$\begin{pmatrix} \alpha & b' & c' \\ b'^* & 0 & 0 \\ c'^* & 0 & \Upsilon \end{pmatrix}$$

where $\alpha \in H_r$, $b' \in \mathrm{Mat}(r \times n_2, \mathbf{C})$, $c' \in \mathrm{Mat}(r \times (n_3 + n_4), \mathbf{C})$ and

$$\Upsilon = \begin{pmatrix} \mathbf{1}_{n_3} & 0 \\ 0 & -\mathbf{1}_{n_4} \end{pmatrix}.$$

Using Lemma 3.6, we see that x is conjugate under the action of G_s to an element of the form

$$\begin{pmatrix} \alpha'' & b'' & 0 \\ b''^* & 0 & 0 \\ 0 & 0 & \Upsilon \end{pmatrix},$$

with $\alpha'' \in H_r$, $b'' \in \mathrm{Mat}(r \times n_2, \mathbf{C})$.

STEP 3. Assume now that

$$x = \begin{pmatrix} \alpha & b & 0 \\ b^* & 0 & 0 \\ 0 & 0 & \Upsilon \end{pmatrix}$$

with $\alpha \in H_r$ and $b \in \mathrm{Mat}(r \times n_2, \mathbf{C})$. Recall that

$$x + iy = \begin{pmatrix} \alpha + i\mathbf{1}_r & b & 0 \\ b^* & 0 & 0 \\ 0 & 0 & \Upsilon \end{pmatrix}$$

is assumed to be invertible. This shows that $\mathrm{rank}(b) = n_2$. So we may apply Lemma 3.7 to see that x is conjugate under G_r to an element of the form

$$\begin{pmatrix} \beta & 0 & 0 & 0 \\ 0 & 0 & \mathbf{1}_{n_2} & 0 \\ 0 & \mathbf{1}_{n_2} & 0 & 0 \\ 0 & 0 & 0 & \Upsilon \end{pmatrix}$$

with $\beta \in H_{r-n_2}$.

STEP 4. Set $n_1 = r - n_2$. The last step is just to put the element $\beta \in H_{n_1}$ in diagonal form under the action of $\mathrm{U}(n_1)$. Up to minor rearrangements of the matrix, this shows that any $\mathrm{GL}(q, \mathbf{C})$-orbit in $\widetilde{T}_q$ contains an element of the form $\Lambda(\lambda_1, \ldots, \lambda_{n_1}, n_2, n_3, n_4)$.

STEP 5. It remains to show that two Λ's are not conjugate under $GL(q, \mathbf{C})$. The angular matrix associated to $\Lambda(\lambda_1, \dots, \lambda_{n_1}, n_2, n_3, n_4)$ is

$$\begin{pmatrix} \frac{\lambda_1+i}{\lambda_1-i} &&&&&&&&&& \\ & \ddots &&&&&&&&& \\ && \frac{\lambda_{n_1}+i}{\lambda_{n_1}-i} &&&&&&&& \\ &&& 1 & 0 &&&&&& \\ &&& 2i & 1 &&&&&& \\ &&&&& \ddots &&&&& \\ &&&&&& 1 & 0 &&& \\ &&&&&& 2i & 1 &&& \\ &&&&&&&& 1 && \\ &&&&&&&&& \ddots & \\ &&&&&&&&&& 1 \end{pmatrix}$$

where there are n_2 2×2 submatrices $\begin{pmatrix} 1 & 0 \\ 2i & 1 \end{pmatrix}$, and $n_3 + n_4$ diagonal elements equal to 1. From the Jordan normal form theorem, we deduce that if $\Lambda(\lambda_1, \dots, \lambda_{n_1}, n_2, n_3, n_4)$ and $\Lambda(\lambda'_1, \dots, \lambda'_{n_1}, n'_2, n'_3, n'_4)$ are in a same $GL(q, \mathbf{C})$-orbit, then $n_1 = n'_1$, $\lambda_j = \lambda'_j$ for all $j, 1 \le j \le n_1$, $n_2 = n'_2$ and $n_3 + n_4 = n'_3 + n'_4$. Now the matrix $\Lambda(\lambda_1, \dots, \lambda_{n_1}, n_2, n_3, n_4) = L + iM$ and $\Lambda' = L' + iM'$, with $L, L', M, M' \in H_n$. As Λ and Λ' are supposed to be in the same $GL(q, \mathbf{C})$-orbit, L and L' are also in the same $GL(q, \mathbf{C})$-orbit, and so they must have the same signature. This forces $n_3 = n'_3$ and $n_4 = n'_4$, and hence $\Lambda = \Lambda'$.

We can now give the solution to the orbit problem we addressed at the end of Section 2. Recall that for any integer r such that $0 \le r \le q$ we defined

$$\widetilde{T}_q^{(r)} = \{z = x + iy \mid y \in \overline{\Omega}_q,\ \operatorname{rank}(y) \le r,\ z \text{ invertible}\}.$$

LEMMA 3.8. *Let n_1, n_2, n_3, n_4 be four integers such that*

$$n_1 + 2n_2 + n_3 + n_4 = q,$$

and let $\lambda_1, \dots, \lambda_{n_1}$ be n_1 real numbers. Then the standard matrix $\Lambda = \Lambda(\lambda_1, \dots, \lambda_{n_1}, n_2, n_3, n_4)$ belongs to $\widetilde{T}_q^{(r)}$ if and only if $n_1 + n_2 \le r$.

In fact the rank of $\frac{1}{2i}(\Lambda - \Lambda^*)$ is $n_1 + n_2$.

THEOREM 3.9. *Any* $\mathrm{GL}(q,\mathbf{C})$*-orbit in* $\widetilde{T}_q^{(r)}$ *contains a unique standard matrix* $\Lambda((\lambda_1,\dots,\lambda_{n_1}, n_2, n_3, n_4)$ *with* $n_1+n_2\le r$.

We now want an analog of Theorem 3.3. As we have already noticed, the conjugacy class of the angular matrix does not determine the orbit of the matrix. We need a finer invariant, which we will construct now.

LEMMA 3.10. *The space* $\widetilde{T}_q$ *is connected and simply connected.*

Proof. As T_q is connected and $T_q\subset\widetilde{T}_q\subset\overline{T_q}$, the space $\widetilde{T}_q$ is connected. Take $i\mathbf{1}_q$ as base point in $\widetilde{T}_q$, and observe that for any $z\in\widetilde{T}_q$ and any $s>0$, $z+is\mathbf{1}_q$ is in T_q. So if $(\gamma(t), t\in[0,1])$ is a path in $\widetilde{T}_q$ starting and ending at $i\mathbf{1}_q$ then we can deform it by homotopy to $\gamma_s(t)=\gamma(t)+is(s-1)\mathbf{1}_q$, which for $s>0$ is a path inside T_q. But T_q as a tube-type domain is simply connected. □

The function $z\mapsto\det(z)$ is a continuous function from $\widetilde{T}_q$ into $\mathbf{C}^*$. From Lemma 3.10, there exists a unique continuous determination of the argument of $\det(z)$ denoted by $\arg\det\colon\widetilde{T}_q\longrightarrow\mathbf{R}$ such that $\arg\det i\mathbf{1}_q=q\frac{\pi}{2}$. If $Y\in\Omega_q$, then $\arg\det iy=q\frac{\pi}{2}$. If $z\in\widetilde{T}_q$ and $g\in\mathrm{GL}(q,\mathbf{C})$, then $\det gzg^*=|\det g|^2\det z$, and $gi\mathbf{1}_qg^*=igg^*\in i\Omega_q$, so that

$$\arg\det gzg^*=\arg\det z\,.$$

This provides a new invariant for the action of $\mathrm{GL}(q,\mathbf{C})$ on $\widetilde{T}_q$.

LEMMA 3.11. *Let* $\Lambda=\Lambda(\lambda_1,\dots,\lambda_{n_1},n_2,n_3,n_4)$. *Then*

$$\arg\det\Lambda=\arg(\lambda_1+i)+\cdots+\arg(\lambda_{n_1}+i)+n_2\pi+\dot{n}_4\pi \tag{23}$$

where arg *is used for the principal determination of the argument of a non-zero complex number.*

Proof. We need to describe a continuous path from $i\mathbf{1}_q$ to Λ inside $\widetilde{T}_q$. For clarity of exposition, we describe successively the path for each diagonal block (either a one-dimensional or a two-dimensional submatrix) of Λ, and compute the contribution of each block to the function $\arg\det$.

For a block of the form $\lambda+i$, with $\lambda\in\mathbf{R}$ we use the path $t\mapsto t\lambda+i$, $0\le t\le 1$, and so the contribution of this block is $\arg(\lambda+i)$.

For a block of the form $\begin{pmatrix} i & 1 \\ 1 & 0 \end{pmatrix}$, we use the path

$$t \mapsto \begin{pmatrix} i & t \\ t & i(1-t^2) \end{pmatrix}, \; 0 \leq t \leq 1 .$$

The corresponding determinant of this 2×2-block is constant along the path and equal to -1. Hence the contribution of this block is $2\frac{\pi}{2} = \pi$.

For a block of the form 1, we use the path $t \mapsto e^{i\frac{\pi}{2}(1-t)}$, $0 \leq t \leq 1$, and we see that the corresponding contribution is 0.

For a block of the form -1, we use the path $t \mapsto e^{i\frac{\pi}{2}(1+t)}$, $0 \leq t \leq 1$, and we see that the corresponding contribution is π.

Putting together the contribution of the blocks, we get the result. □

COROLLARY 3.12. *Let* Λ *and* Λ' *be two standard matrices. Assume that their angular matrices coincide and that* $\arg\det\Lambda = \arg\det\Lambda'$. *Then* $\Lambda = \Lambda'$.

Proof. In fact we noticed that the equality of angular matrices implies the equality of the parameters except for $n_3 = n_3'$ and $n_4 = n_4'$. But from (23), we see that the equality of the determination of the arguments of the determinants implies $n_4 = n_4'$ (and hence $n_3 = n_3'$). □

Now we can state the conclusion of this section, which is a consequence of Theorem 3.4 and Corollary 3.12.

THEOREM 3.13. *Let* $z, z' \in \widetilde{T}_q$, *and assume that the angular matrices of* z *and* z' *are conjugate, and that* $\arg\det z = \arg\det z'$. *Then* z *and* z' *belong to the same orbit under the action of* $\mathrm{GL}(q, \mathbf{C})$.

REMARK. Let $z \in \widetilde{T}_q$. Let $a = {z^*}^{-1} z$. Then

$$\det a = \frac{\det z}{\overline{\det z}} = |\det z|^{-2} (\det z)^2 .$$

So $2 \arg\det z$ is a determination of $\arg(\det a)$. If z and z' are two matrices in $\widetilde{T}_q$ with the same angular matrix, then $\arg\det z$ and $\arg\det z'$ differ by an integral multiple of π. So the new invariant needed to characterize the orbits under $\mathrm{GL}(q, \mathbf{C})$ has to be regarded as a $\mathbf{Z}$-valued function. In this sense, it is a generalization of the signature.