Necessary and Sufficient Condition for the Quaternion Vector Measure

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Abstract—In this paper, the definitions of the quaternion measure and the quaternion vector measure are introduced. The relation between the quaternion measure and the complex vector measure as well as the relation between the quaternion linear functional and the complex linear functional are discussed respectively. By using these relations, the necessary and sufficient condition to determine the quaternion vector measure is given.

Keywords—Quaternion, Quaternion measure, Quaternion vector measure, Quaternion Banach space, Quaternion linear functional.

I. INTRODUCTION

Let \( X \) be a Banach space over complex field and \((\Omega, \Sigma)\) be a measurable space. A function \( m: \Omega \rightarrow X \) is said to be a vector measure if \( m \) satisfies

\[
m(\bigcup_{n=1}^{\infty} E_n) = \sum_{n=1}^{\infty} m(E_n)
\]

for all sequences of pairwise disjoint sets \( \{E_n\}_{n=1}^{\infty} \subseteq \Sigma \), where the series is convergent in the norm topology of \( X \).

The study of vector measure is a very active field of research, and it is already very old, too. For the case of vector measure on \( \sigma \)-algebra \( \Sigma \) to the real or complex Banach space, in 1936, J. A. Clarkson [1] used vector measure-theoretic ideas to prove that many Banach spaces do not admit equivalent uniformly convex norms. In 1938, I. Gel’fand [2] also used vector measure-theoretic methods to prove that \( L_1([0, 1]) \) is not isomorphic to a dual of a Banach space. From the forties to the mid-sixties, many mathematicians, for example, R. G. Bartle [3], N. Dinculeanu and I. Kluvánek [4], N. Dunford and J. T. Schwartz [5], J. Lindenstrauss and A. Pełczyński [6], etc., gave many classical results on vector measure.


Consider the differences between the complex Banach space and the quaternion Banach space, and the applications of the quaternion measure and quaternion vector measure to quantum mechanics [17], we naturally discuss the following question.

Question. Does the quaternion vector measure have some properties which are analogous to that of complex vector measure?

In this paper, we introduce the definition of the quaternion vector measure, and discuss the above question, give some properties on the quaternion measure and quaternion vector measure. By using these obtained properties, we also prove that Lemma 3, Theorem 1 and 2, which are necessary and sufficient conditions for the quaternion measure and the quaternion vector measure. Moreover, Theorem 1 and 2 are similar to complex vector measure case.

II. PRELIMINARIES

Let \( \mathbb{R} \) and \( \mathbb{C} \) be the real number field and the complex number field, respectively. The quaternion skew field, denoted by \( \mathbb{H} \), is the set of all elements with the form \( q_0 + q_1 i + q_2 j + q_3 k \), where \( q_0, q_1, q_2 \) and \( q_3 \in \mathbb{R} \), moreover,

\[
i^2 = j^2 = k^2 = i j k = -1;
\]

\[
ij = -ji = k, jk = -kj = i, ki = -ik = j.
\]

It is clear that \( \mathbb{R} \subseteq \mathbb{C} \subseteq \mathbb{H} \), and the multiplication operation is noncommutative in \( \mathbb{H} \), it is easy to imply that \( j e = \tau j \) for any complex number \( e \). Furthermore, for every \( q \in \mathbb{H} \), \( q \) can be uniquely expressed as

\[
q = q_1 + q_2 j,
\]

where \( q_1, q_2 \in \mathbb{C} \) for \( q = q_0 + q_1 i + q_2 j + q_3 k \in \mathbb{H} \). The conjugate and norm of \( q \) are respectively defined as

\[
q^* = q_0 - q_1 i - q_2 j - q_3 k,
\]

\[
|q| = \sqrt{q_0^2 + q_1^2 + q_2^2 + q_3^2}.
\]

Let \( M_n(\mathbb{C}) \) (resp. \( M_n(\mathbb{H}) \)) be the collection of all \( n \times n \) matrices with complex entries (resp. quaternion entries). For \( A \in M_n(\mathbb{H}) \), then there exist \( A_1 \) and \( A_2 \) in \( M_n(\mathbb{C}) \) such that \( A = A_1 + A_2 j \) and such representation is unique. We call the \( 2n \times 2n \) complex matrix

\[
\begin{bmatrix}
A_1 & A_2 \\
-A_2 & A_1
\end{bmatrix}
\]

as the complex adjoint matrix of the quaternion matrix \( A \) and denote it by \( \chi_A \).
Analogy to the classical measure theory, we extend the definition of complex measure to the quaternion setting and have Definition 1.

**Definition 1.** Let \((\Omega, \Sigma)\) be a measurable space. A function \(\mu : \Sigma \rightarrow \mathbb{H}\) is called a quaternion measure if
\[
\mu\left(\bigcup_{n=1}^{\infty} E_n\right) = \sum_{n=1}^{\infty} \mu(E_n)
\]
whenever \(\{E_n\}_{n=1}^{\infty} \subseteq \Sigma\) is a sequence of pairwise disjoint sets.

In this paper, we call the Banach space over complex field as the complex Banach space and the vector measure from \(\Sigma\) to the complex Banach space as the complex vector measure.

Similar to the definition of the complex vector measure, we introduce the definition of a quaternion vector measure.

**Definition 2.** Let \((\Omega, \Sigma)\) be a measurable space and \(X_{\mathbb{H}}\) be a quaternion Banach space. A function \(m : \Sigma \rightarrow X_{\mathbb{H}}\) is called a quaternion vector measure if \(m\) satisfies
\[
m\left(\bigcup_{n=1}^{\infty} E_n\right) = \sum_{n=1}^{\infty} m(E_n)
\]
for all sequences of pairwise disjoint sets \(\{E_n\}_{n=1}^{\infty} \subseteq \Sigma\), where the series is convergent in the norm topology of \(X_{\mathbb{H}}\).

### III. Necessary and Sufficient Conditions for the Quaternion Vector Measure

Owing to the quaternion multiplication being noncommutative, according to the left scalar multiplication and the right scalar multiplication, we call a vector space over the quaternion field \(\mathbb{H}\) as a left or right quaternion vector space. For convenience, the left quaternion vector space and the left quaternion Banach space are also said to be the quaternion vector space and the quaternion Banach space, respectively.

Throughout this paper, we assume that \(X_{\mathbb{H}}\) is a quaternion vector space, \(\{e_i\}_{i=1}^{\infty} \subseteq X_{\mathbb{H}}\) is a basis of \(X_{\mathbb{H}}\),
\[
X_{\mathbb{C}} = \{x \mid x = \sum_{i=1}^{\infty} \alpha_i e_i, \alpha_i \in \mathbb{C}\},
\]
\[
Y_{\mathbb{C}} = \{y \mid y = \sum_{i=1}^{\infty} \alpha_i je_i, \alpha_i \in \mathbb{C}\},
\]
then \(X_{\mathbb{C}}\) and \(Y_{\mathbb{C}}\) are vector spaces over \(\mathbb{C}\) with respect to the addition operation and the scalar multiplication operation of \(X_{\mathbb{H}}\), respectively.

In order to give some necessary and sufficient conditions for the quaternion measure and quaternion vector measure, we need the following auxiliary lemmas.

**Lemma 1.** Let \(a_n, b_n \in \mathbb{C}\) and \(q_n = a_n + b_n j\), then the series \(\sum_{n=1}^{\infty} q_n\) is convergent if and only if \(\sum_{n=1}^{\infty} a_n\) and \(\sum_{n=1}^{\infty} b_n\) are convergent, respectively.

**Proof.** Let \(n \rightarrow \infty\), then the conclusion is valid.

**Lemma 2.** Under the hypotheses of \(X_{\mathbb{H}}\), then \(X_{\mathbb{H}} = X_{\mathbb{C}} + Y_{\mathbb{C}}\).

Moreover, if \(X_{\mathbb{H}}\) is a quaternion Banach space, then \(X_{\mathbb{C}}\) and \(Y_{\mathbb{C}}\) are complex Banach spaces under the norm of \(X_{\mathbb{H}}\).

**Proof.** Let \(x \in X_{\mathbb{H}}\), then \(x = \sum_{n=1}^{\infty} \alpha_i e_i, \alpha_i \in \mathbb{H}\). By (1), then \(\alpha_i\) can be represented as \(\alpha_i = \alpha_{i1} + \alpha_{i2} j\), where \(\alpha_{i1}, \alpha_{i2} \in \mathbb{C}\). By simple computation, then
\[
x = \sum_{n=1}^{\infty} \alpha_{i1} e_i + \sum_{n=1}^{\infty} \alpha_{i2} e_i.
\]

By using the definitions of \(X_{\mathbb{C}}\) and \(Y_{\mathbb{C}}\), we have
\[
X_{\mathbb{H}} = X_{\mathbb{C}} + Y_{\mathbb{C}}.
\]

Let \(\{y_n\}_{n=1}^{\infty} \subseteq X_{\mathbb{C}}\), then \(y_n = \sum_{i=1}^{\infty} \beta_{i} e_i\), where \(\beta_{i} \in \mathbb{C}\). If \(\{y_n\}_{n=1}^{\infty}\) is a cauchy sequence of the complex vector space \(X_{\mathbb{C}}\) under the norm of \(X_{\mathbb{H}}\), note that \(X_{\mathbb{H}}\) is a Banach space, then \(y_n\) is convergent to \(y \in X_{\mathbb{H}}\).

Let \(y = \sum_{n=1}^{\infty} \alpha_i e_i\), \(\alpha_i \in \mathbb{H}\). By (1), there exist \(\alpha_{i1}\) and \(\alpha_{i2} \in \mathbb{C}\) such that \(\alpha_{i1} = \alpha_{i1} + \alpha_{i2} j\), thus
\[
y_n - y = \sum_{i=1}^{\infty} (\beta_{i} - \alpha_{i1}) e_i - \sum_{i=1}^{\infty} \alpha_{i2} j e_i.
\]

Since \(y_n\) is convergent to \(y\), we have
\[
\lim_{n \rightarrow \infty} \sum_{i=1}^{\infty} (\beta_{i} - \alpha_{i1}) e_i = \sum_{i=1}^{\infty} \alpha_{i2} j e_i.
\]

Note that \(\{e_i\}_{i=1}^{\infty}\) is the basis of \(X_{\mathbb{C}}\) and \(X_{\mathbb{C}} \subseteq X_{\mathbb{H}}\), hence \(\{e_i\}_{i=1}^{\infty}\) is also basis of the complex vector space \(X_{\mathbb{C}}\). Since \(\beta_{i} - \alpha_{i1} \in \mathbb{C}\) and \(e_i\) is a basis of \(X_{\mathbb{C}}\), we imply that \(\alpha_{i2} = 0\) for \(i = 1, 2, \ldots\). Thus \(y = \sum_{n=1}^{\infty} \alpha_{i1} e_i\), and \(y \in X_{\mathbb{C}}\). So \(X_{\mathbb{C}}\) is a Banach space.

Analogue of the above proof, we can also show that \(Y_{\mathbb{C}}\) is a Banach space. Here we omit its proof.

**Lemma 3.** Let \((\Omega, \Sigma)\) be a measurable space and \(X_{\mathbb{C}}\) a quaternion Banach space. Then \(m : \Sigma \rightarrow X_{\mathbb{H}}\) is a quaternion vector measure if and only if there exist complex vector measures \(m_1 : \Sigma \rightarrow X_{\mathbb{C}}\) and \(m_2 : \Sigma \rightarrow Y_{\mathbb{C}}\) such that
\[
m = m_1 + m_2.
\]

**Proof.** For each \(E \in \Sigma\), since \(m : \Sigma \rightarrow X_{\mathbb{H}}\), by Lemma 2, \(X_{\mathbb{C}}\) and \(Y_{\mathbb{C}}\) are complex Banach spaces under the norm of \(X_{\mathbb{H}}\), moreover, \(m(E)\) can be uniquely expressed as
\[
m(E) = m_1(E) + m_2(E),
\]
where
\[
m_1(E) = \sum_{n=1}^{\infty} m_1(e_i) e_i \in X_{\mathbb{C}}, m_1(E) \in \mathbb{C},
\]
\[
m_2(E) = \sum_{n=1}^{\infty} m_2(e_i) e_i \in Y_{\mathbb{C}}, m_2(E) \in \mathbb{C}.
\]

Note that \(m : \Sigma \rightarrow X_{\mathbb{H}}\) is a function, thus \(m_1 : \Sigma \rightarrow X_{\mathbb{C}}\) and \(m_2 : \Sigma \rightarrow Y_{\mathbb{C}}\) are well defined and
\[
m = m_1 + m_2.
\]

For all sequences of pairwise disjoint sets \(\{E_n\}_{n=1}^{\infty} \subseteq \Sigma\), by (3), then
\[
m(\bigcup_{n=1}^{\infty} E_n) = m_1(\bigcup_{n=1}^{\infty} E_n) + m_2(\bigcup_{n=1}^{\infty} E_n).
\]

According to the uniqueness of the representation of the equality \(m(E) = m_1(E) + m_2(E)\)
\[
\sum_{n=1}^{\infty} m(E_n) = m_1(\sum_{n=1}^{\infty} E_n) + m_2(\sum_{n=1}^{\infty} E_n),
\]
the proof follows.

In following, We list a result in [18] as our Lemma 4.

**Lemma 4 ([18]).** Let \(A, B \in M_n(\mathbb{H})\), then
\[
(1). \chi_{A+B} = \chi_A + \chi_B,
\]
\[
(2). \|A\| = \|\chi_A\|.
\]

Theorem 1 reflects a relation between the quaternion measure and the complex vector measure.

**Theorem 1.** Let \((\Omega, \Sigma)\) be a measurable space, \(\mu_{\mathbb{H}} : \Sigma \rightarrow \mathbb{H}\) be a function. Then \(\mu_{\mathbb{H}}\) is a quaternion measure if and only if \(m : \Sigma \rightarrow M_2(\mathbb{C})\) defined by \(m(E) = \chi_{\mu(E)}\) is a complex vector measure.

**Proof.** By (1), then \(\mu_{\mathbb{H}}(E)\) can be uniquely expressed as
\[
\mu_{\mathbb{H}}(E) = \mu_{\mathbb{H}}^{(1)}(E) + \mu_{\mathbb{H}}^{(2)}(E) j
\]
where $\mu^{(1)}_H(E), \mu^{(2)}_H(E) \in \mathbb{C}$.

By (2), then
\[
m(E) = \chi_{\mu^n}(E) = \begin{bmatrix} \mu^{(1)}_H(E) & \mu^{(2)}_H(E) \\ -\mu^{(2)}_H(E) & \mu^{(1)}_H(E) \end{bmatrix}.
\]

(5)

Sufficiency: For all sequences of pairwise disjoint sets $\{E_n\}_{n=1}^\infty \subseteq \Sigma$, since $m : \Sigma \to M_2(\mathbb{C})$ is a complex vector measure, we have
\[
m(\bigcup_{n=1}^\infty E_n) = \sum_{n=1}^\infty m(E_n)
\]
in the norm topology of $M_2(\mathbb{C})$. By (5),
\[
m(\bigcup_{n=1}^\infty E_n) = \begin{bmatrix} \mu^{(1)}_H(\bigcup_{n=1}^\infty E_n) \\ -\mu^{(2)}_H(\bigcup_{n=1}^\infty E_n) \\ \mu^{(2)}_H(\bigcup_{n=1}^\infty E_n) \\ -\mu^{(1)}_H(\bigcup_{n=1}^\infty E_n) \end{bmatrix}.
\]

(6)

\[
\sum_{n=1}^\infty m(E_n) = \lim_{n \to \infty} m(\bigcup_{n=1}^n E_n)
\]
\[
= \lim_{n \to \infty} \begin{bmatrix} \sum_{n=1}^n \mu^{(1)}_H(E_n) \\ -\sum_{n=1}^n \mu^{(2)}_H(E_n) \\ \sum_{n=1}^n \mu^{(2)}_H(E_n) \\ -\sum_{n=1}^n \mu^{(1)}_H(E_n) \end{bmatrix}
\]
\[
= \begin{bmatrix} \mu^{(1)}_H(\bigcup_{n=1}^\infty E_n) \\ -\mu^{(2)}_H(\bigcup_{n=1}^\infty E_n) \\ \mu^{(2)}_H(\bigcup_{n=1}^\infty E_n) \\ -\mu^{(1)}_H(\bigcup_{n=1}^\infty E_n) \end{bmatrix}.
\]

Consequently,
\[
\mu^{(1)}_H(\bigcup_{n=1}^\infty E_n) = \sum_{n=1}^\infty \mu^{(1)}_H(E_n),
\]
\[
\mu^{(2)}_H(\bigcup_{n=1}^\infty E_n) = \sum_{n=1}^\infty \mu^{(2)}_H(E_n).
\]

Thus, $\mu^{(1)}_H$ and $\mu^{(2)}_H$ are complex measures from $\Sigma$ to $\mathbb{C}$. By (4) and Definition 1, then $\mu_H$ is a quaternion measure. The sufficiency is proved.

Necessity: If $\mu_H : \Sigma \to \mathbb{H}$ is a quaternion measure, note that the representation of the equality (4) is unique, by Lemma 1, we can imply that $\mu^{(1)}_H$ and $\mu^{(2)}_H$ are complex measures.

Let $\{E_n\}_{n=1}^\infty$ be a sequence of pairwise disjoint sets in $\Sigma$, note that $\mu^{(1)}_H$ and $\mu^{(2)}_H$ are complex measures, by Lemma 4, we can imply that
\[
\| \chi_{\mu^n}(E_n) - \sum_{i=1}^\infty \mu^{(i)}_H(E_i) \| = 0.
\]

(7)

By (5), then $m : \Sigma \to M_2(\mathbb{C})$ defined by $m(E) = \chi_{\mu^n}(E)$ is a complex vector measure.

In the rest of this section, we will give a necessary and sufficient condition for quaternion vector measure. Due to the noncommutative of quaternion, there are two types of linear functional on quaternion Banach space, left linear functional and right linear functional. Here we are interested in the left linear functional, so the introduction to the right linear functional is omitted.

A left quaternion linear functional on a quaternion Banach space $X$ is a map $f : X \to \mathbb{H}$ satisfying
\[
f(\alpha x + \beta y) = \alpha f(x) + \beta f(y)
\]
for all $x, y \in X$ and $\alpha, \beta \in \mathbb{H}$. For convenience, we also call the left quaternion linear functional as the quaternion linear functional.

Lemma 5. Let $X_H$ be a quaternion Banach space and $f : X_C \to \mathbb{C}$ a bounded complex linear functional. If
\[
F(x) = f(x) - jf(jx_2)
\]
where $x \in X_H$ with form $x = x_1 + x_2$, $x_1 \in X_C$ and $x_2 \in X_C$, then $F : X_H \to \mathbb{H}$ is a bounded quaternion linear functional.

Proof. Let $x, y \in X_H$, by Lemma 2, then
\[
x = x_1 + x_2, \quad y = y_1 + y_2,
\]
where $x_1, y_1 \in X_C$ and $x_2, y_2 \in X_C$.

Note that $jx_2 \in X_C$, thus
\[
F(x) = f(x_1) - jf(jx_2)
\]
is well defined for each $x \in X_H$.

Let $\alpha, \beta \in \mathbb{C}$, since $\alpha x = \alpha x_1 + \alpha x_2$, $jx = jx_1 + jx_2$, $f : X_C \to \mathbb{C}$ is a linear functional, by simple computation, we can imply that
\[
F(x + y) = F(x) + F(y),
\]
\[
F(\alpha x) = f(\alpha x_1) - jf(j\alpha x_2)
\]
\[
= \alpha f(x_1) - j\alpha f(jx_2)
\]
\[
= \alpha f(x_1) - \alpha jf(jx_2)
\]
\[
= \alpha f(x_1) - \alpha f(jx_2)
\]
\[
= \alpha F(x).
\]
\[
F(jx_2) = f(jx_2) - jf(j_2 jx_1)
\]
\[
= f(jx_2) + jf(x_1)
\]
\[
= jf(jx_2 + x_1)
\]
\[
= jF(x).
\]

By the above arguments, we have that
\[
F((\alpha + \beta) x) = F(\alpha x) + F(\beta x)
\]
\[
= (\alpha + \beta) F(x).
\]

Thus, $F$ is a linear functional on $X_H$. Note that
\[
|f(x)| \leq |F(x)| \leq |f(x)| + |f(jx)| \leq 2||f|||x||.
\]

Hence, $F(x)$ is a bounded quaternion linear functional. □

Lemma 6. Let $X_H$ be the quaternion Banach space and $F$ a bounded quaternion linear functional on $X_H$, then there exist bounded complex linear functionals $f_1$ and $f_2 : X_H \to \mathbb{C}$ such that
\[
F(x) = f_1(x) + f_2(x)j
\]
for each $x \in X_H$.

Proof. Since $F$ is a bounded quaternion linear functional, for each $x \in X_H$, by (1), then $F(x)$ can be uniquely expressed as
\[
F(x) = f_1(x) + f_2(x)j,
\]
where $f_1(x), f_2(x) \in \mathbb{C}$.

Let $x, y \in X_H$, note that $F(x + y) = F(x) + F(y)$, by (6), we can imply that
\[
F(x + y) = f_1(x + y) + f_2(x + y)j,
\]
\[
F(x) + F(y) = f_1(x) + f_2(x)j + f_1(y) + f_2(y)j.
\]
\[
= (f_1(x) + f_1(y)) + (f_2(x) + f_2(y))j.
\]

Hence
\[
f_1(x + y) = f_1(x) + f_1(y),
\]
\[
f_2(x + y) = f_2(x) + f_2(y).
\]

Let $\alpha \in \mathbb{C}$, since $F(\alpha x) = \alpha F(x)$, by (6), we have
\[
F(\alpha x) = f_1(\alpha x) + f_2(\alpha x)j,
\]
\[
\alpha F(x) = \alpha f_1(x) + \alpha f_2(x)j.
\]

Hence, $f_1(\alpha x) = \alpha f_1(x)$, $f_2(\alpha x) = \alpha f_2(x)$. Consequently, $f_1$ and $f_2$ are complex linear functionals from $X_H$ to $\mathbb{C}$.

Note that
\[
|f_1(x)| < |F(x)|, |f_2(x)| < |F(x)|.
\]

Then, $f_1$ and $f_2$ are bounded complex linear functionals. □
Lemma 7. Let $(\Omega, \Sigma)$ be a measurable space and $X_H$ a quaternion Banach space. If $m$, $m_1$, and $m_2$ are the same as Lemma 3, and $m : \Sigma \to X_H$ satisfies that $F(m) : \Sigma \to \mathbb{H}$ defined by $E \to F(m(E))$ is a quaternion measure for each bounded quaternion linear functional $F$. Then $m_1 : \Sigma \to X_C$ and $m_2 : \Sigma \to Y_C$ are complex vector measures, respectively.

Proof. Let $f : X_C \to \mathbb{C}$ be an arbitrary bounded complex linear functional, by Lemma 5, then

$$F(x) = f(x_1) - f(j(x_2)),$$

is a bounded quaternion linear functional on $X_H$, where $x \in X_H$ with the form $x = x_1 + x_2$, $x_1 \in X_C$ and $x_2 \in Y_C$.

By Lemma 3, for every $E \in \mathcal{S}$, then

$$m(E) = m_1(E) + m_2(E),$$

$m_1(E) \in X_C$ and $m_2(E) \in Y_C$. Hence

$$F(m(E)) = f(m_1(E)) - f(j(m_2(E))).$$

Let $\{E_n\}_{n=1}^{\infty} \subseteq \mathcal{S}$ be a pairwise disjoint sequence of sets, since $F(m(E))$ is a quaternion measure, we have

$$F(m(\bigcup_{i=1}^{\infty} E_n)) = \sum_{i=1}^{\infty} F(m(E_n)).$$

Note that

$$F(m(\bigcup_{i=1}^{\infty} E_n)) = f(m_1(\bigcup_{i=1}^{\infty} E_n)) - f(j(m_2(\bigcup_{i=1}^{\infty} E_n))).$$

By Lemma 1, then

$$f(m_1(\bigcup_{i=1}^{\infty} E_n)) = \sum_{i=1}^{\infty} f(m_1(E_n)).$$

Hence, for each sequence $\{E_n\}_{n=1}^{\infty} \subseteq \mathcal{S}$ of pairwise disjoint sets, we have

$$F(m(\bigcup_{i=1}^{\infty} E_n)) = \sum_{i=1}^{\infty} F(m(E_n)).$$

Consequently, the function $F(m) : \Sigma \to \mathbb{H}$ defined by $E \to F(m(E))$ is a quaternion measure. The proof for the necessity of Theorem 2 is complete.

Sufficiency: By using Lemma 7 and Lemma 3, then $m$ is a quaternion vector measure. The proof is completed.

By Theorem 1 and 2, the following corollary is valid.

Corollary 1. With the same notations as Theorem 2. Then $m : \Sigma \to X_H$ is a quaternionic vector measure if and only if $X_F(m(E)) : \Sigma \to M_2(\mathbb{C})$ is a complex vector measure.

Acknowledgement

This work was supported by Natural Science Foundation of Shandong province in China (Grant No. BS2013SF014).

References