E-NEWSLETTER

March 2018 issue

THE SOCIETY OF ACOUSTICS SINGAPORE

Official Address:5 Derbyshire Road, #04-05, Singapore 309461
Tel: 67913242 and Mobile No. 90932730 Fax: 62990485
E-mail: wsgan@metaultrasound.com
Website: www.acousticssingapore.com

Registration No: 0331/1989
Year of Registration: 1989

President: Dr Gan Woon Siong
Secretary: Prof Y F Zhou
Treasurer: Dr Venu

CONTENTS

I.CONFERENCE NEWS

The 25th International Congress on Sound and Vibration(ICSV25) will be held in Hiroshima , Japan from 8 to 12 July 2017.

Woon Siong Gan will be organising three structured sessions on:

1. **Nonlinear acoustics and vibration**
2. **Acoustic metamaterials & phononic crystals: fundamentals and applications**
3. **Sound propagation in curvilinear spacetime**

Please visit www.icsv25.org for more informations.

The 13 th Western Pacific Acoustics Conference will be held from 11-15 November ,2018 in New Delhi, India.

The abstracts deadline is 15 May 2018.

Woon Siong Gan will be organising two structured sessions at this conference on:

1.Nonlinear acoustics & vibration

2.Acoustic metamaterials & phononic crystals: fundamentals and applications.

Please visit the website: www.wespac2018.org.in for more informations.

II.ANNONCEMENTS

The Society of Acoustics will be sending out invoices to members with outstanding membership subscriptions. Members are encouraged to make payment in support of the Society.

The E-Newsletters will be made available to industrial contacts in an effort to promote the activities of the Society.

The Society is also exploring the possibility of organising talks and other professional events in collaboration with acoustic societies of other countries.

Membership Certificates will soon be made available to all members who had made full payments of membership dues

The Society aims to increase membership by inviting all persons, including those from the institution of higher learning and other related societies such as the Institute of Architects, Singapore and the members of the mechanical engineering division of the Institution of Engineers, Singapore who are qualified in the various field of Acoustics to join our Society.

We are especially keen to invite students to join our society and we are establishing the Youth Chapter soon.

III.INTERNATIONAL ACOUSTICS NEWS

Woon Siong Gan was recently elected as a Director of the International Institute of Acoustics and Vibration(IIAV) for the period 2018 to 2022.

IV.MEMBERSHIP SUBSCRIPTION

Fellow	**S$70**
Member	**S$50**
Associate	**S$30**
Student	**S$15**
Corporate	**S$200**

FEE BASED ON ANNUAL RATE

FOR MORE INFORMATION PLEASE CONTACT: Dr. Woon Siong Gan at email: wsgan5@gmail.com

Membership application forms can be downloaded from the society website: www.acousticssingapore.com. Please complete and email to wsgan5@gmail.com

V.ARTICLE

History of Gauge Invariance in Physics

Woon Siong Gan

1 The Roots of Gauge Invariance

Gauge invariance is a very important principle in physics. The underlying theory of the standard model of particle physics, quantum electrodynamics, quantum chromodynamics, theory of superconductivity, theory of superfluids, and the general theory of relativity are all gauge theories.The oldest gauge theory in physics is Maxwell’s equations of electrodynamic wave equations. The gauge conditions in Maxwell’s equations are:

$$\mathbf{A}' = \mathbf{A} + \nabla\chi \qquad (1)$$

$$\phi' = \phi - \frac{1}{c}\frac{\partial \chi}{\partial t}$$
(2)

where **A** = vector potential, ϕ= scalar potential and χ = gauge function. Both **A** and ϕ are gauge fields.
Equations (1) and (2) are conditions for the gauge transformations in the Maxwell's equations of electromagnetic theory. The concept of gauge invariance arose due to the discovery that different forms of the vector potential **A** produce the same observable forces. The vector potential **A** is the key gauge field. This means that Maxwell's electromagnetic equations are invariant under the gauge transformations of eqns (1) and (2). This is an abelian group with the group symmetry U(1). These are gauge invariance applied to classical physics.

After the arrival of quantum mechanics, an additional gauge condition was added on by Vladimir Fock[1] in 1926:

$$\Psi' = \psi \exp(ie\chi/\hbar c)$$
(3)

where ψ = wave function, e = electronic charge, h = Planck's constant, and c = light velocity.
This means that in order to maintain the same form of the Schrodinger equation, the wave function has to be multiplied by the space-time dependent local phase.

Subsequently in 1929, Hermann Weyl [2]combined gauge transformations of (1),(2), and (3) to produce the concept of the invariance of a theory known as gauge invariance or gauge symmetry. The name gauge invariance was introduced by H. Weyl[2]. The gauge symmetry of the quantum version of the electromagnetic theory, known as quantum electrodynamics is abelian symmetry described by the U(1) group. The first work on non-abelian gauge symmetry SU(2)xU(1) was due to Oscar Klein[3] in 1938 applying to the electromagnetic and weak interactions. In 1954, Chen-Ning Yang and Robert Mills[4] rediscovered non-Abelian gauge symmetry and applied to strong interactions. In 1960s, there was the Glashow, Weinberg , and Salam [5,6,7]'s paper on the non-abelian electroweak theory. The discovery in CERN in 1983 of the heavy W and Z bosons confirm the correctness of the electroweak theory. In the 1970s , a non-abelian gauge theory for strong interaction of quarks and gluons was developed[5]. One of its creators Murray Gell-Mann[8] gave the theory the name of quantum chromodynamics(QCD) and is based on the SU(3) group. QCD and the electroweak theory form the basis of the standard model which accounts for all the three main forces of nature: strong, electromagnetic and weak forces with the exception of the fourth force the gravitational force.
Hence gauge invariance plays a key role in physics. Gauge invariance is the underlying principle of the current Standard Model of strong and electroweak interactions.

2. The Vector Potential A

The vector potential A is the key gauge field. Vector potential was introduced by Ludvig V Lorenz in 1867. By the beginning of the twentieth century, due to the contributions by Heaviside, Lorentz, Clausius, and Hertz, on localized charges in motion forming currents, the role of the scalar and vector potentials and their interaction with charged particles. The formal structure of electromagnetic theory and the concept of gauge transformations were founded. In the 1920s with the arrival of quantum mechanics, the interaction of charged particles with a time-varying electromagnetic fields, the issue of the arbitrariness of the electromagnetic potentials arose. The study of the consequences of of the change in the electromagnetic potentials on the quantum mechanical wave function transformed into a general principle that defines quantum gauge fields.

Faraday discovered electromagnetic induction in 1839....This means relative motion of a magnet near a closed circuit induces a momentary flow of current. This started the close link between electric and magnetic fields. Franz E Neumann in 1845 and 1847 analyzed electromagnetic induction in one circuit due to the relative motion of nearby circuits and magnets. He is credited to invent the vector potential. His formula for the induced current allowed one to sense the vector potential:

$$\text{Magnetic interaction energy } \mathrm{W} = \frac{I}{c}\oint_{C} \; n^{o}\mathbf{A}'\mathrm{dS} \tag{4}$$

$$\text{with } \mathbf{A}'(\mathrm{x}) = \frac{I'}{c}\oint_{C'} \frac{n'}{r}\mathrm{dS}' \tag{5}$$

where C,C' = circuits, A' = vector potential of the current I' flowing in circuit C', **r** = distance = **x** – **x**' where **x** and **x**' are coordinates of d**S** = **n**dS and d**S**' = **n**dS, I and I' = currents and **dS,** d**S**' = elements.

In 1857 Kirchoff showed the relation between the scalar potential ϕ and the vector potential A:

$$\mathbf{A} = \frac{1}{c}\frac{\partial \phi}{\partial t} \tag{6}$$

3 Milestones of the Development of Gauge Invariance Principle in Physics

3.1 Maxwell's Role in developing the Gauge Theory

Maxwell developed the electromotive force as :

$$\mathrm{c}\mathbf{E} = -\frac{dA}{dt} = -\frac{\partial A}{\partial t} + (\mathbf{v}.\nabla)\mathbf{A} \tag{7}$$

and the gauge transformation: $\mathbf{A}' = \mathbf{A} - \nabla\chi$
(8)

In the meantime, Lorentz mentioned that his retarded potentials **A** and ϕ are solutions of Maxwell’s equations and that the following gauge condition must be satisfied:

$$\nabla . \mathbf{A} + \frac{1}{c^2}\frac{\partial \phi}{\partial t} = 0$$

(9)

This is now known as the Lorentz gauge condition.

3.2 The Role of V Fock[1]in the History of Gauge Invariance [1926b]-The Quantum Era

1926 saw the arrival of quantum mechanics and the emergence of the principle of gauge invariance in quantum Vladimir Fock[1] discovered the symmetry under gauge transformations (1),(2), and (3) of the quantum mechanical system of a charged particle interacting with electromagnetic fields.). His paper was submitted on 30 July 1926 and published on 2 October 1926 This means that the Schrӧdinger equation is invariant under the gauge transformations (1), (2), and (3). He showed that the equation is invariant under the change in the vector and scalar potentials provided that the gauge transformation condition in (3) is fulfilled. Also in this paper, he first discussed the special-relativistic wave equation of his earlier paper with electromagnetic interactions and addressed the effect of the change in the vector and scalar potentials (1 and 2). He went on to treat a five-dimensional general-relativistic formalism, similar to but independent of Oscar Klein[2]. Also he added the following note after the proof of this paper: “While this note was in proof, the beautiful work of Oskar Klein [published on 10 July] arrived in Leningrad,” and that the principal results were identical.

The idea of an abelian gradient transformation was first conceived by V Fock [1] in 1926 . He also discovered that the electromagnetic interaction of charged particles has a gradient invariance in the framework of quantum mechanics. These transformation and invariance were respectively named Eichtransformation and Eichinvarianz by H Weyl [2]in 1929 (the German verb *zu eichen* means *to gauge*).

.3.3 The Role of Hermann Weyl [2]in the History of Gauge Invariance[1929]

In 1929, shortly after the formulation of QED, Weyl[2] wrote a paper relating electromagnetism to matter field. He discovered In the abstract of this important paper [2] he states “The

Dirac field equations for ψ together with the Maxwell equations for the four potentials fp of the electromagnetic field have an invariance property ....the equations remain invariant when one makes simultaneous substitutions $\psi \rightarrow ei\lambda\psi$, $fp \rightarrow fp - \partial\lambda/\partial xp$. It seems that this new principle of gauge invariance, which follows not from speculation but from experiment, tells us that the electromagnetic field is a necessary accompanying phenomenon not of gravitation, but of material wave field represented by ψ.”

From this paper, the concept of gauge invariance was born. Weyl’s route to gauge invariance illustrates the fact that theoretical proposals must be verified by experiments.

Historically, Weyl[2]’s 1929 papers were a watershed. They enshrined fundamentally the modern principle of gauge invariance, in which the existence of the 4-vector potentials (and field strengths) follow from the requirement of the invariance of the matter equations under gauge transformations such as (1), (2), and (3) of the matter fields. Gauge invariance is the touchstone of the theory of gauge fields, so dominant in theoretical physics in the second half of the 20th century

3.4 The Yang Mills Theory

Yang Mills theory is a gauge theory based on the SU(N) group. In 1954 Chen Ning and Robert Mills[4] extended the concept of abelian group, U(1) group for quantum electrodynamics to non-abelian groups to explain strong interactions. They developed their theory without realizing that the PhD student Ronald Shaw[9] under Abdus Salam at Cambridge University also developed the same at the same time Due to the requirement of particles must be massless to fulfill gauge invariance as criticized by W. Pauli, the theory did not receive attention till 1960 with the arrival of spontaneous symmetry breaking when the concept of particles acquiring mass through symmetry breaking was put forward initially by Jeffrey Goldstone[10],, Yoichiro Nambu, and Giovanni Jona-Lasinio.[11,12,13].

This rekindled the interest in the Yang–Mills[4] theory studies which proved successful in the formulation of both electroweak unification and quantum chromodynamics (QCD).

The electroweak interaction is described by SU(2) × U(1) symmetry non-abelian group while QCD is an SU(3) non-abelian group Yang–Mills theory. The electroweak theory SU(3) is the combination of SU(2) group with U(1) group. Here quantum electrodynamics SU(2)U(1)(QED) is described by the U(1) group, and replaced in the unified electroweak theory by a U(1) group representing a weak hypercharge rather than electric charge. The massless bosons from the SU(2) × U(1) electroweak theory interact after spontaneous symmetry breaking to produce the photon field and the 3 massive weak bosons The Standard Model combines the unified electroweak interaction, unifyingStandard Modelthe weak and electromagnetic interaction with the strong interaction through the non-abelian symmetry group SU(2) × U(1) × SU(3).Experimentally, the unification of strong, electromagnetic, and weak interactions is shown by the observation of the running of the coupling constants believed that they all converge to a single value at very high energies. The first manifestation of the physical application of the Yang Mills theory is the Weinberg-Salam model [7,6] a

SU(2)xU(1) Yang Mills theory, of electroweak theory unifying electromagnetic interaction with weak interaction where the gauge fields are identified as the photon fields with the hypothetical massive vector mesons mediating weak interactions. The Yang Mills[4] theory was developed to describe strong interactions. The significance of this theory is that it is the only model which can account for asymptotic freedom[14,15] which means interaction forces become negligible at short distances.

Subsequently, the SU(3) Yang Mills[4] theory [5]also known as quantum chromodynamics, coupled to quarks provide the realistic theoretical framework for the MIT/SLAC experiments on high energy lepton-nucleon scattering. These show the physical significance of the non-abelian gauge fields which although are not identified with the observed particles, they provide the glue that keeps the quarks bound strongly inside hadrons so strongly to be permanently confined.

3.5 The Glashow Feinberg Salam ‘s Electroweak Theory

In 1960s, Glashow, Weinberg, and Salam [5,6,7]developed the non-abelian SU(2)x U(1) symmetry group theory to unify the electromagnetic interaction and the weak interaction. The unification is accomplished under a SU(2)xU(1) gauge group. The verification of the theory was experimentally established in two stages.:the first being the discovery of neutral currents in neutrino scattering by the Gargamelle collaboration in 1973, and the second in 1983 by the UA1 and the UA2 collaborations involving the discovery of the W and Z gauge bosons in proton–antiproton collisions at the converted super proton synchrotron. In 1999, Gerardus 't Hooft and Martinus Veltman [16,17]were awarded the Nobel prize for demonstrating that the electroweak theory is renormalizable.

3.6 The Gell-Mann ‘s Quantum Chromodynamics for Strong Interaction

Quantum chromodynamics(QCD) is a gauge theory based on the non-abelian SU(3)group. It is the theory of stong interaction between quarks and gluons. Murray Gellmann [8] coined the word quark. Quarks and gluons are are the fundamental particles that make up the composite hadrons like pion, neutron, and proton. In QCD, the word colour is a property in QCD which is the analog of electric charge in QED.Gluons are the equivalent of protons in QED .They are the force carriers of the theory, like photons the carriers of electromagnetic force in QED. QCD is an important part of the Standard Model. Over the years there is a large number of experiments verifying the theory.

Every field theory of particle physics has symmetry properties whose existence is deduced from observations. Symmetries can be divided into:

local symmetries that act independently at each point in spacetime. Each such symmetry is the basis of a gauge theory that requires the introduction of its own gauge bosons.

global symmetries, which are symmetries whose operations must be applied simultaneously to all points of spacetime. An example of global symmetry is reflection symmetry.

QCD is a gauge theory of the SU(3) non-abelian gauge group obtained with the colour charge defining a local symmetry.Since the strong interaction does not discriminate between different flavours of quark, QCD has approximate flavour symmetry, broken by the differing masses of the quarks.

3.7 W. S. Gan's Introduction of Gauge Invariance to Acoustic Wave Equation of Motion

In 2007 W. S. Gan[18] introduced gauge invariance or gauge theory into acoustic wave equation of motion. This will enable a deeper understanding of the properties of acoustic fields especially its symmetry properties and new phenomena to be discovered in acoustics. The starting point is due to the several similarities between electromagnetic waves and acoustics waves dues to the common wave phenomena. The introduction of gauge invariance into electromagnetic waves has enable discoveries of several important theories such as the Yang Mills theory, electroweak theory, and quantum chrodynamics. Likewise for acoustic waves, the introduction of gauge invariance, should give rise to important new theories in the future, and bring acoustics to the highest arena. W.S.Gan[18] introduced the two gauge conditions (1) and (2) from electromagnetic wave equation into acoustic wave equation:.

W.S.Gan [18] extended the gauge invariance property of the Maxwell's equation for electromagnetic theory to the acoustic field equations. Gauge invariance which includes symmetries is a basic property of field theory which covers strong nuclear forces, electromagnetic force, and gravitational force. In extending gauge invariance approach to acoustic fields, it will be a more sophisticated approach than the vector theory of acoustic fields. We address the symmetry properties of the acoustic field equations, the application of gauge invariance to negative refraction and interpretation of the inhomogeneous wave equation in terms of gauge invariance. Gauge invariance has long been applied to electromagnetic wave theory in Maxwell's equations. . Due to the similarities between electromagnetic waves and acoustic waves,as both are wave phenomena, the interpretation of acoustic fields in terms of gauge invariance will provide more understanding of the acoustic fields and throw lights on new potential applications.

The applications of gauge invariance to the Maxwell's equation will give rise to several important development on standard model of the particle physics and to superconductivity and superfluidity. The introduction of gauge invariance to the acoustic wave equation of motion on the other hand will find applications in condensed matter physics. An example is the acoustic metamaterial is an outcome of the symmetry properties of the acoustic field. Also gauge invariance can be introduced in electron-phonon interaction with application in spintronics[19].. Other applications are in time reversal acoustics and that the phonon is a Goldstone mode.

In electromagnetic theory, the Lorentz gauge condition is given as

$$\nabla \cdot \vec{A} + \frac{1}{c^2}\frac{\partial \phi}{\partial t} = 0 \tag{10}$$

With Lorentz condition, the acoustic wave equation can be expressed in terms of the scalar and vector potentials as:

$$\nabla^2 \vec{A} - \frac{1}{V_s^2}\frac{\partial^2 \vec{A}}{\partial t^2} = 0 \tag{11}$$

$$\nabla^2 \phi - \frac{1}{V_l^2}\frac{\partial^2 \phi}{\partial t^2} = 0 \tag{12}$$

where $V_l = (c_{11}|\rho)^{1/2}$.

This shows that the acoustic fields T and V can be expressed in terms of the gauge fields A and ϕ. This is a more accurate method of obtaining solutions for the acoustic fields.

The Lorentz gauge condition has the advantage of introducing complete symmetry between the scalar and vector potentials i.e. it makes both potentials satisfy the same wave equation as that obeyed by the fields. Equation (11) and (12) are a symmetrical set of equations.

By using the analogy of momentum density P as equivalent to B and stress field T as equivalent to E~, one has

$$\vec{T} = -\nabla\phi - \frac{\partial \vec{A}}{\partial t} \tag{13}$$

and

$$P = \nabla \times A \tag{14}$$

By inspection of Eqs. (13) and (14), one finds that the resultant stress field and momentum density field are unchanged by transformation of the following types :which are gauge conditions:

$$\mathbf{A}' = \mathbf{A} + \nabla\chi \qquad (15)$$

$$\phi' = \phi - \frac{1}{c}\frac{\partial\chi}{\partial t} \qquad (16)$$

shown in (2.10 and in (2.2) where φ is a function of the coordinates and the time. This means that if any physical law involving elastic energy interactions is to be expressed in terms of the general elastic energy potential A~ and φ, then such a physical law must be unaffected by a transformation of that given by Eqns. (15) and (16). These transformations are usually known as gauge transformations, and a physical law that is invariant under such a transformation is said to be gauge invariant. The property of gauge invariance ensures that the physical law will not lead to consequences that cannot be expressed in the field formulation of the interaction of elastic properties. (15) and (16) are the gauge conditions of the acoustic wave equation/

From the above field theory approach, we find that both the vector fields V and T can be expressed in terms of a scalar potential and a vector potential.

The application of gauge invariance approach to acoustic fields to negative diffraction:

Veselago[20] derived the negative refraction theory from the consideration of negative permittivity and negative permeability, and is limited only to isotropic materials and electromagnetic wave. Here one extends his theory to acoustic wave and to anisotropic materials such as piezoelectric materials. Gauge invariance is used in this study. It is well known that an important property of gauge invariance is symmetry.

.

3.8 Gauge Invariance in Acoustic Wave Equation in Curvilinear Spacetime

The above gauge invariance treatments from Sections 2.3.1 to .2.3.7 are all meant for the flat spacetime or the Minkowski spacetime. Here one extends the treatment of gauge invariance in acoustic wave equation to curvilinear spacetime. The first step one has to start with the relativistic acoustic wave equation for curvilinear spacetime and express it in terms of the vector potential and the scalar potential.

4.Applications of Gauge Invariance to Acoustic Wave Equations

Application of gauge invariance to electromagnetic wave equations has manifested in applications in particle physics such as the standard model of particle physics. Quantum electrodynamics, quantum chromodynamics and the theories of superconductivity and superfluids are all gauge theories. Application of gauge invariance to acoustic wave equation on the other hand will find applications in condensed matter physics such as in interactions such as electron-phonon interaction etc.

Other applications of gauge invariance in acoustic wave equation are:

Symmetry of anisotropic solids is an example of local symmetry and is a form of SU(2) symmetry of non-Abelian group. Symmetry of isotropic solids is a form of U(1) symmetry and is global symmetry. In an anisotropic material, the compliance and stiffness possess rotational symmetry. Compliance and stiffness together describe the intrinsic elastic properties of the medium. The compliance constant describes the elastic properties of a medium in a manner analogous to the description of its electrical properties by the permittivity matrix elements. If the medium itself is symmetric with respect to a particular transformation of coordinates, then the compliance and stiffness matrices must themselves be unchanged by the same transformation. Symmetries for anisotropic media are much more complicated than for the isotropic case.

Negative refraction: When rotating in the clockwise direction, it gives rise to lefthanded phenomenon such as the negative refraction. When rotating in the anticlockwise direction, it give rise to the righthanded phenomenon such as positive refraction. Due to rotational symmetry, both the righthanded phenomenon and lefthanded phenomenon satisfy the acoustic field equations. The stress field, the velocity field and the acoustic Poynting vector together form a righthanded triplet or a lefthanded triplet depending on the direction of energy flow or the direction of the Poynting vector. According to parity conservation, acoustic law at the deepest level, there is no differentiation of righthanded and lefthanded treatment. The performance of an object and that of its mirror image will satisfy the same law of physics. The negative refraction in fact is a mirror image of the positive refraction.

Veselago[20] derived the negative refraction theory from the consideration of negative permittivity and negative permeability, and is limited only to isotropic materials and electromagnetic wave. Using gauge invariance, one extends his theory to acoustic wave and to anisotropic materials . It is well known that an important property of gauge invariance is symmetry

References

1. Fock, V.: Uber die invariante Form der Wellen- und der Bewegungsgleichungen f ù ur í einen geladenen Massenpunkt," Zeit. fur Physik 3 í **9**, 226-232(1926b).[subm. 30 July 1926, publ. 2 October 1926]

2. Weyl,H.: Elektron und gravitation. I. Z. Phys. **56**, 330 (1929).
3. Klein, O.:On the theory of charged fields,” in New theories in physics, Conference organized in collaboration with the International Union of Physics and the Polish Intellectual Cooperation Committee (Warsaw, May 30th- June 3rd, 1938),(1938).
4. Yang,C N., and Mills,R.L.: Conservation of isotopic spin and isospin gauge invariance. Phys. Rev. **96**, 191-195(1954).
5. Glashow, S. :The renormalizability of vector meson interactions. Nucl. Phys.**10**, 107(1959)..Glashow, S. :The renormalizability of vector meson interactions. Nucl. Phys*.***10**, 107(1959)..
6. Salam, A.; Ward, J. C.: :W and electromagnetic interactions. .Nuovo Cimento*. **11** (4): 568–577,(1959).*
7. Weinberg, S : . A model of leptons". Phys. Rev. Lett*.**19**:, 1264–66(1967).*
8. Gell-Mann, M. : The eightfold way: A theory of strong interaction symmetry" (No. TID-12608; CTSL-20). California Inst. of Tech., Pasadena. Synchrotron Lab (online).(1961).
9. Shaw R: Invariance under general isotopic gauge transformations Cambridge University PhD thesis, unpublished(1955)..
10. Goldstone, J.: Field theories with " superconductor " solutions. Il Nuovo Cimento. **19**: 154–164(1961).
11. Nambu, Y (1960). "Quasiparticles and gauge invariance in the theory of superconductivity**".** Physical Review. **117**:, 648–663(1960)
12. Nambu, Y.; and Jona-Lasinio, G.*:* Dynamical model of elementary particles based on an analogy with superconductivity. I". Physical Review*. **122**:,*345-358(1961).
13. Nambu, Y.; Jona-Lasinio, G.: Dynamical Model of Elementary Particles Based on an Analogy with Superconductivity. II . Physical Review. **124**: 246–254.(1961).
14. Gross,D., and Wilczek,F.,Phys.Rev.Lette.**30**,1343,(1973).
15. Politzer,D.: Phys.Rev.Lett.,**30**,1346,(1973)
16. ‘tHooft,G.: The renomalization procedure for Yang-Mills fields”, Ph.D Thesis, Utrecht University (1972);
17 ‘tHooft,G., and Veltman,M.: Regularization and renormalization of gauge Fields” Nucl Phys. **B44**, 189 (1972).
18. Gan,W.S. : Gauge invariance approach to acoustic fields. In: AkiYAMA,I.(ed.) Acoustical Imaging,vol.29,pp.389-394,Springer, The Netherlands(2007).
19. Dartora,C.A.,and Cabrera,G.G.: The electron-phonon interaction from fundamental local gauge symmetries in solids. Journal of Physics A: Mathematical and Theoretical,**47**,No.3,(2013).
20. Veselago,V.G. : The electrodynamics of substances with simultaneously negative values of ε and μ" Sov. Phys. Usp. **10** (4): 509–514(1968)..

VI.REPORT ON CONFERENCES

The Regional Conference on Acoustics and Vibration (RECAV) organised by the Society of Acoustics(Singapore) and the Association of Acoustics and Vibration Indonesia(AAVI) was successfully held in Bali,Indonsia from 27 to 28 Nov 2017. There were 110 presentations from 14 countries with 60% of them from Indonesia. There were also some 18 exhibition booths. This reflected strong local participation and the international nature of the conference.

VII. BID FOR FUTURE INTERNATIONAL CONFERENCES

Riding on the success of Wespac 2015, the society is bidding to host the International Congress on Acoustics(ICA) in Singapore in 2025 and to host the International Congress on Sound and Vibration(ICSV) in Singapore in 2021

Government Bodies

www.mom.gov.sg

www.nea.gov.sg

www.lta.gov.sg

Technical and Research Sites

Corporate Sites

www.metaultrasound.com

www.noisecontrols.com

(The Society welcomes interested parties to contribute relevant websites to the above e useful links. For more information, please contact us. Thank you.)

Disclaimers

President: **Woon Siong Gan**
E-Newsletter compiled by: **Woon Siong Gan**