Extracting electromagnetic energy from the nonlinear Earth as a self-pumped phase conjugate mirror

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At the beginning of the 20th century, Nikola Tesla constructed and attempted to complete a giant Earth transmitter on Long Island, New York, which he believed would energize the Earth itself into giant, amplified standing waves which could be "tapped" at other locations around the globe to provide cheap and amplified electrical power, all fueled by enormous energy freely fed into the standing wave from the Earth itself. Tesla's U.S. Patent No. 1,119,732, "Apparatus for transmitting electrical energy", on his "Magnifying Transmitter", was granted on Dec. 1, 1914, after nearly thirteen years of struggle with the Patent Office. His patent No. 645,576, "System of transmission of electrical energy", Mar. 20, 1900 and his Patent No. 649,621, "Apparatus for transmission of electrical energy", May 15, 1900, were also related to the magnifying transmitter.

In this paper we present a possible means of converting the Earth into a self-pumped phase conjugate mirror (SPPCM), containing a powerful spherical standing scalar EM wave. The SPPCM Earth then produces a self-powered, highly amplified phase conjugate EM replica wave in response to another input EM wave of nominal power transmitted separately into the Earth from any point.

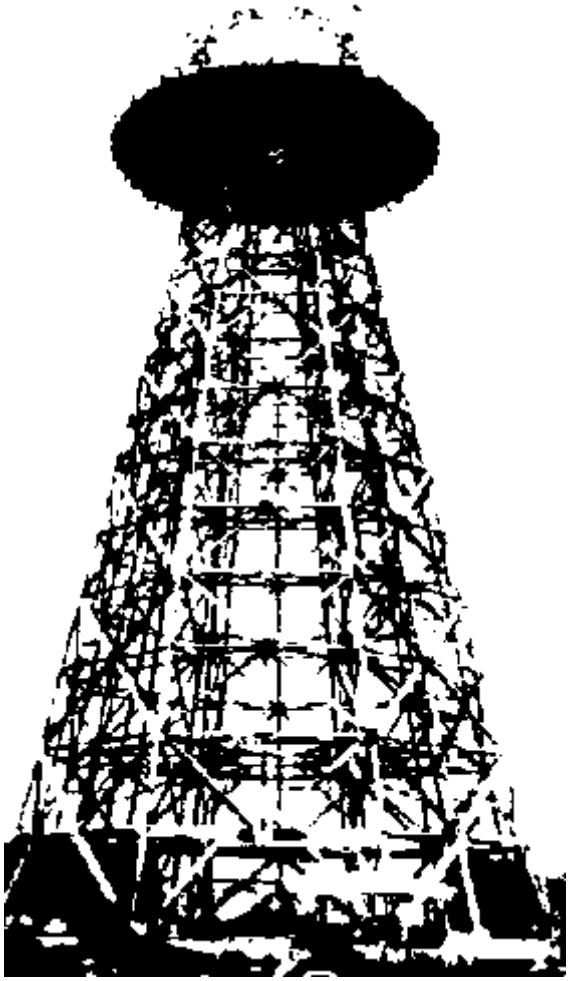
We point out the special characteristics of this standing scalar EM wave and the Earth's reaction, both in the four spatial dimensions (1-3 and 5) of 5-dimensional Kaluza-Klein space and in the time (4th) dimension. (1)

Also we point out that quantization results in a reciprocating wave between electromechanical stress in the four spatial dimensions and canonical stress in the time dimension. This allows the stressed nonlinear Earth to act as a self-pumped phase conjugate mirror (2) so that stress energy of the Earth feeds energy into the standing scalar EM wave, resulting in very high energy gain and production of a very powerful electrogravitational resonance condition (standing wave) in the Earth itself.

This powerful resonant standing wave is then "tapped" in accordance with standard 4-wave mixing theory (3) to produce a highly amplified phase conjugate replica in response to a relatively small input signal from any distant Earth-coupled transmitter on the Earth's surface. (4) The phase conjugate replica signal is coupled back to the distant transmitter/receiver site where it is received, processed and fed into the electrical power grid to distribute electrical power.

A single inducing transmitter can be used to energize the entire Earth on a single frequency or "energy channel" (5). This channel can be tapped by numerous extraction transceivers around the Earth, furnishing energy from the Earth itself at each extraction site. Additional inducing

transmitters can be added on different frequencies, to provide additional energy extraction channels (6).



Nikola Tesla's Magnifying Transmitter built on Long Island, New York

In this manner, enormous amounts of clean electrical energy, free from present Earth-polluting generator systems, can be cheaply and continuously extracted from the massive energy of the Earth itself and used to power the requirements of the nations and citizens of the Earth.

The primary energy source (Earth's heat and stress energy) is replenished from the Sun, the Earth's own internal reactions, and the vacuum itself; therefore, this method provides a permanent, clean and self replenishing source of electrical power for all humankind.

Establishing a Standing Scalar EM Wave in the Earth

Let us momentarily treat the Earth as an isotropic but broadly resonant nonlinear medium. We will consider the Earth's deep interior, which is under intense heat and pressure, as a special kind of cathode. We will attempt to produce a transformation of the Earth into a special triode, so that we may then introduce a relatively small "grid signal" and gate highly amplified energy from the Earth's interior self-powered cathode to an external plate load on the surface.

We envision a powerful transmitter operating at a fixed frequency within the Earth's resonant frequency band, transmitting a signal vertically into the Earth, and utilizing a deeply buried ground plane for good Earth coupling (Figure 1). Due to Newton's Third Law (which we will further discuss shortly), a phase-reversed and opposite EM wave (Figure 2) is also produced. We assume that the two opposing EM waves are to function as a "pump wave", well-known in nonlinear optics as the pumped phase conjugate mirror theory (7).

The nonlinear Earth medium acts as a modulator, causing the two opposite waves to mutually modulate each other and lock together as a single wave. This resulting scalar EM wave is a resonant, standing spherical wave with zero E and B electromagnetic force field resultants. This

standing scalar EM wave is set up throughout the spherical Earth medium (Figure 3). This wave has zero-resultant E and B fields, but consists of oscillations in the stress energy density of the vacuum itself. It is, therefore, a gravitational wave and travels through the atomic nuclei of the Earth as its transmission medium, rather than through the atomic orbital electron shells (8).

For each of the two EM vector wave components of the standing scalar wave, the reverse piezoelectric and magnetic nature of the Earth causes a concomitant standing mechanical wave to be produced, and again Newton's Third Law causes an opposing mechanical wave to also be produced.

At any small point in the Earth, opposing and balanced mechanical forces are produced which, being mechanically superposed by the nonlinear mass application point, sum to a zero mechanical translation resultant.

However, even though the summed mechanical wave has a zero-vector resultant with regards to translation, each of its paired and opposite internal mechanical force components forms a mechanical stress. Since the two zero-summed mechanical components are rhythmically varying in a directly opposing manner, together they constitute a rhythmically varying mechanical stress wave at each and every point. The summation of all such rhythmic, time-synchronous stress pairs at each point produces the total mechanical stress wave at that point in the Earth - much like repeatedly squeezing a ball in place between the outstretched fingers of one's two hands, without translating the ball. An analogy comparing the E and B field electromagnetic translation and swirl forces, and the electrogravitational "squeeze" potential G is shown in Figure 4.

Production of a Standing Wave in Four Spatial Dimensions

Further, this rhythmically varying mechanical stress wave in the Earth is a standing wave, and is spirally co-incident with the standing scalar wave.

Thus there is formed a single, phase-locked, oscillating, standing EM/mechanical stress wave in the Earth medium, but this stress wave has no external electromagnetic field or mechanical strain vector.

In both cases (scalar EM wave and scalar mechanical stress wave), the wave constitutes a special kind of Kaluza-Klein gravitational wave. The scalar EM component constitutes an electrogravitational potential standing wave in the 5th dimension, since all EM is fifth-dimensional in the well-known Kaluza-Klein theory. The mechanical (3-space) component constitutes a standing, ordinary gravitational wave in our normal 3-space. Taken together, the two phase-locked waves constitute a full gravitational standing wave in the 4 spatial dimensions of KK 5-space, 3-space and the 5th dimension. We call this "spatial-only gravitational wave" in 5-space a k-wave, and we call the four spatial dimensions k-space.

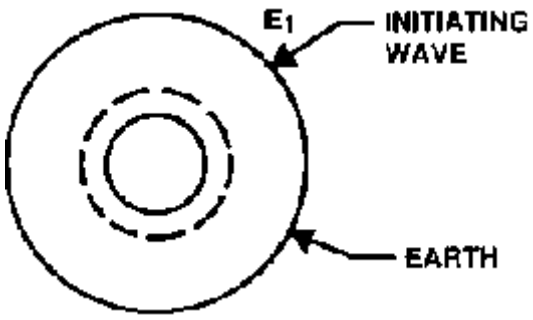


Figure 1. Input into a cathode earth

[NOTE: PUMP WAVE IS A STANDING WHITTAKER WAVE]

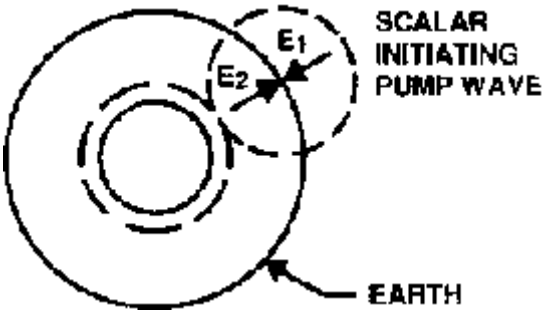


Figure 2. Input + reaction + modulation

[NOTE: STANDING WHITTAKER WAVES]

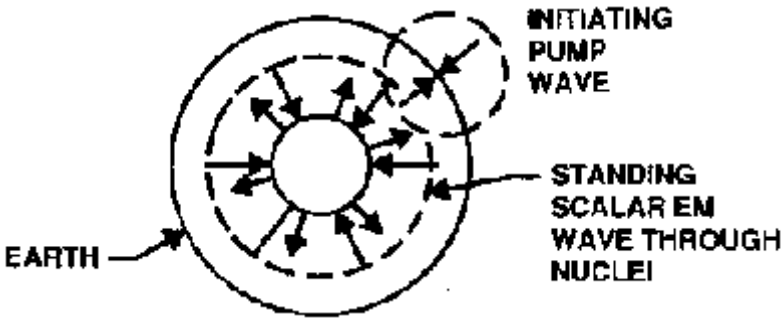


Figure 3. Spherical scalar wave in internal earth stresses

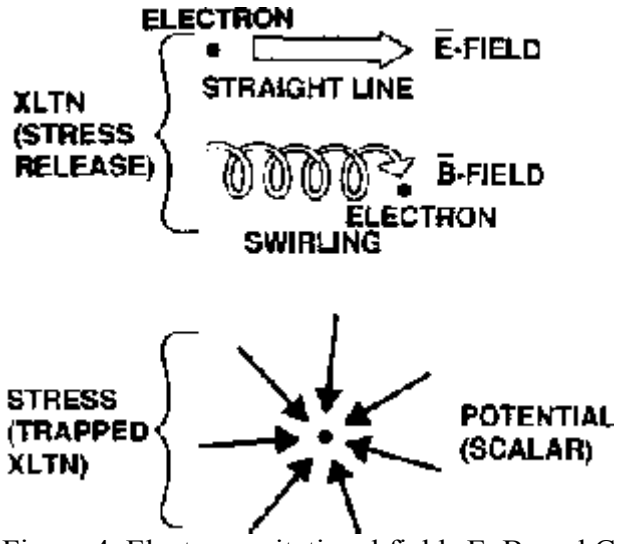


Figure 4. Electrogravitational fields E, B. and G

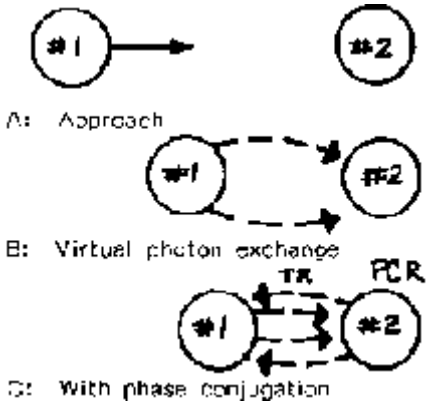


Figure 5. Newton's Third Law

NOTE: emission of TR/PCR does not affect momentum of ball No. 2

Formation of a Canonical Wave of Time Stress

Now we examine the situation in the remaining KK dimension, the fourth or "time" dimension, caused by the creation of the k-wave.

In the five-dimensional KK model, we may regard a fundamental quantum as existing in five dimensions. This quantum consists of the product of two parts, one in the 4th dimension (time) and one in the combined 3-space and 5th dimension. (The 5th dimension in KK theory is "wrapped around" each point in 3-space, and intimately related to it.) Again, we shall refer to ordinary 3-space and the 5th dimension, taken together, as "k-space". Note that our two phase-locked "3-spatial and 5th dimensional stress waves" constitute a stress wave in k-space.

Since the 5-space quantum must possess a constant magnitude, then when a regular stress oscillation is established in the k-space dimensional component of the 5-d quantum, an inverse stress oscillation also canonically exists in its 4th dimensions, or time, component.

Thus in 5-space we have actually created and established two phase-locked canonical stress waves: one stress wave in k-space, and its inverse replica in time - which we shall call the "t-wave".

When the magnitude of the k-wave is increasing, the magnitude of the t-wave is decreasing, and vice versa. We shall call this canonical symbiosis of the two waves the reciprocal wave principle. We call the wave itself the reciprocating wave, to accent that stress energy is oscillating back and forth between the time dimension and k-space. We also refer to the reciprocating wave as the r-wave.

Mechanism Producing Relativity and Time Dilation

We point out that this mechanism may actually produce the rotation of a frame of reference, and time dilation, as follows:

When a frame is rotating (the object is accelerating), the accelerated object has an external force acting upon it. By Newton's Third Law, the accelerated object itself also produces an equal and opposite reaction force, acting back upon the system furnishing the accelerating force..

In the accelerated object itself, its mass particles act as nonlinear media, and consequently the object is internally stressed in 3-space.

Quantum mechanics shows that the mechanism transporting the mechanical forces is electromagnetic (it is due to virtual photon exchange at base), and so the object is also stressed electromagnetically, or in the 5th dimension. Hence the object is stressed in k-space.

Since - quantum mechanically - all "static stress" actually exists dynamically by exchange of virtual state flux, a "static" force to the external classical observer is actually due to a dynamic flow at base in the k-space of the change quanta produced.

At "zero velocity", a nonmoving object experiences (and each of its mass particles interacts with) the basic, background virtual particle stress (flux density) of vacuum. When the object is moving through the vacuum at some velocity, it meets a greater virtual particle flux density - much as a moving vehicle in the rain strikes more raindrops then when still. Thus the moving object experiences greater vacuum flux density, hence greater vacuum virtual particle stress.

So when the acceleration on the accelerating object is removed after a higher velocity has been obtained, the dynamic vacuum flux being "met" and interacted with, by the mass particles of the moving object has been increased, and the object is under greater vacuum potential stress.

The reciprocal wave principle applies: the increased internal k-stress in the accelerated object produces a concomitant decrease in the t-stress. Hence accelerating an object to a higher velocity produces time dilation, while at the same time producing length contraction.

The Reciprocating Wave

The reciprocal wave principle and mechanism are directly analogous to an inductive-capacitative oscillatory circuit: in the LC oscillator, electrical change stress is oscillating back and forth between a capacitance and an inductance. Five dimensionally speaking, in the r-wave,

"gravitational stress potential" is oscillating back and forth between mechanical stress in k-space and time stress in the 4th dimension. We shall refer to this fundamental type of oscillatory stress wave as a reciprocating wave or r-wave.

Due to its zero-vector resultant E and B field nature, the r-wave primarily exists in, and acts upon the nucleus of each atom, doing little to the atom's electron shells except "squeeze" the electrons in passage. it-waves are primarily emitted from, and absorbed by, the nucleus of the atom.

When a reciprocating wave is present in a mass object, the k-space component causes the object to act as a pumped phase conjugate mirror (PPCM). As a PPCM, it may be pumped by:

1. mechanical stress,
2. electromagnetic stress,
3. any combination of the two.

Further, standard 4-wave mixing theory may be employed to produce high amplification of the r-wave. If an external signal (such as an oscillating force, which quantum mechanically is electromagnetic and dynamic at its "virtual particle exchange" base level) is applied, then a time-reversed or phase conjugate replica is produced.

For a useful ratio, we shall divide the energy density of the phase conjugate replica wave by the energy density of the external input signal, and call the resulting dimensional constant the gain of the pumped phase conjugate mirror.

In the nominal case, where external pumping is not employed, a gain of unity is experienced. If external pumping by electromagnetic or mechanical stress - or a combination of the two - is applied, then a gain of greater than unity can be readily obtained. For pumping of great magnitude, a very large gain of truly great magnitude can be obtained. In the oscillation condition, for example, the effective theoretical gain of a real system approaches infinity, which simply means that all the available energy in the scalar pump wave appears in the amplified phase conjugate replica output.

Immediately it can be seen that, theoretically, any PPCM device which will utilize environmental heat and/or stress for pumping, can be used with a weak "grid" input as a scavenging device to gather waste heat and stress and convert them into useful, coherent output.

It also follows that any such device is negentropic, since it converts disordered energy into ordered energy. The impact of this type of device upon the second law of thermodynamics is obvious. However, we should state in passing that the conventional second law is stated for positive-time operations only, and the device referred to here is utilizing time reversal (phase conjugated waves). As a gedanken experiment, the exercise strongly suggests that a corollary to the second law - the law of negentropy - is required to address time-reversed situations.

Mechanism Producing Newton's Third Law

The foregoing mechanisms are in fact responsible for producing the reaction force in Newton's Third Law.

For example, in two colliding rigid spheres (Figure 5), when ball one closely approaches to strike ball two, it produces a force in ball two due to its emitted virtual photons being absorbed in the mass particles - particularly the atomic nuclei - of ball two. Being positively charged, the atomic nuclei act as phase conjugate mirrors, and produce and emit a "time-reversed replica" of the virtual photons absorbed as a result of collision with ball one, without themselves changing the momentum of ball two. (It is well-known in phase conjugate mirror theory that the emission of a time-reversed wave by a PCM does not produce a reaction force on the emitting mirror, although absorption of a TR wave does produce a force on the absorbing mirror.) The time-reversed virtual photons emitted by ball two reverse back down the path taken by the input "signal" photons from approaching ball one, and travel back to the nuclei of the atoms in ball one. There they are

absorbed and produce an absorption force (which we observe as a spatially-reversed replica force) in and on ball one.

In a linear situation (uncurved space-time), where nothing is done to interfere with the production and emission of the phase conjugate replica from the ball two "phase conjugate mirror" and its absorption in ball one, then an equal and opposite reaction force is produced in, and on ball one. As can be seen, this is the electromagnetic mechanism that generates Newton's Third Law.

We note in passing that, in a linear situation, whenever work is accomplished on a "receiving" object or system, an equal amount of work is accomplished on the "initiating" object or system. In a nonlinear situation (locally curved space-time), this need not be true since the vacuum now may contain either a sink for, or a source of, energy.

Given this mechanism for Newton's Third Law, if we curve local space-time (tamper with and change the local vacuum's virtual particle flux density), we may directly affect the phase conjugation mechanism and consequently alter the "linear case" Newtonian Third Law. In that case, the reaction force need not be exactly opposite to, nor equal in magnitude to, the action force.

This means that:

1. It is possible to build a Maxwell's Demon (9),
2. the conservation of energy law can be violated (10),
3. it is possible to build a so-called "free energy" device (11).

Conceivably, we may also utilize the nonlinear effect of a locally curved space-time on Newton's Third Law, to electromagnetically produce a unilateral space-drive translation force in and on a vehicle without the ejection of mass, but this is beyond the scope of the present paper.

The Earth as a Self-Pumped Phase Conjugate Mirror

To lend credence to Tesla's magnifying transmitter, we shall now apply these new principles to the situation produced in the Earth by our special standing reciprocal wave, so that almost limitless energy can be obtained for practical use. Bear in mind that we are still modeling an idealized isotropic medium, and the results will still have to be modified to function in the "real" Earth, which normally departs from the isotropic ideal sufficiently to cause destructive damping of our reciprocal wave.

To continue with an idealized Earth model: In the interior of the Earth, the core is considered to be under very great mechanical pressure and so hot that it is molten. It also consists of a great mix of materials, and so constitutes a highly nonlinear material medium.

With the establishment of a reciprocal wave in this idealized nonlinear material medium, a situation exists where,

1) the Earth's core forms an extremely efficient phase conjugate mirror (PCM), and,

2) due to its internal heat and pressure, this PCM is self-pumped with pump waves of extreme magnitude, particularly in the frequency region from slightly above 0 Hertz to 1 - 2 megaHertz. Figure 6 shows the Earth as a self-pumped phase conjugate mirror after initiation.

Further, spherical symmetry exists. The core of the Earth forms a spherical self-pumped phase conjugate mirror, the mid-sphere section of the Earth forms another, and so does the mantle of the Earth. All three self-pumped conjugate mirrors are further cohered together into a single self-pumped phase conjugate mirror system, phase-locked together by the standing reciprocal wave.

Now with a second well-grounded transmitter (part of a transceiver) located at any other point on the Earth's surface, let us transmit a signal into the Earth at the same frequency used by the original transmitter.

A standard 4-wave mixing (FWM) situation now exists, where a powerful "pump" wave (waves 1 and 2 in FWM) is self-furnished by the heat and pressure of the interior of the Earth and the input signal (wave 4 in FWM) is furnished by transmitter number two. According to the well-known FWM principle, in this case a powerfully amplified phase conjugate replica (PCR) signal (wave 3 in FWM) will be returned from the Earth to the transceiver site. (12)

In effect, the Earth has been converted into a giant self-powered triode, and now any distant input site will function as both a grid input and a plate collector for the triode Earth. Figure 7 represents this extraction of a powerfully amplified PCR wave, allowing energy to be extracted directly from the "self-pumped Earth PCM".

At the distant extraction site, a very large, specially tuned LC oscillatory circuit is used to receive the powerful electromagnetic PCR from the Earth, with very high amperage and voltage. Connecting transmission lines conduct the electromagnetic energy to a separate station where the surging power from the pumped Earth is processed by standard techniques and fed onto transmission lines that connect to a large electrical power grid.

According to well-known 4-wave mixing theory, for the oscillation condition (90 degrees), the gain of a pumped phase conjugate mirror approaches such a large number that it may be regarded as nearly infinite. (13)

Very large amounts of electrical power could be extracted from the Earth in this fashion, if the Earth behaved strictly as our idealized isotropic nonlinear medium.

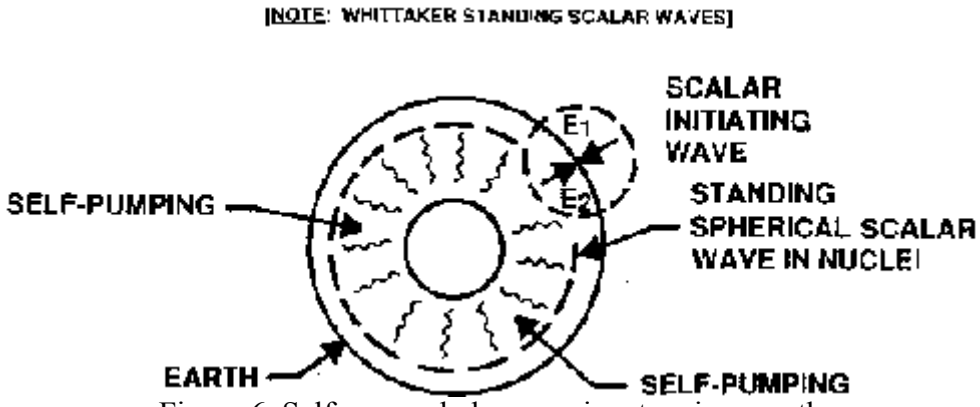


Figure 6. Self-pumped phase conjugate mirror earth

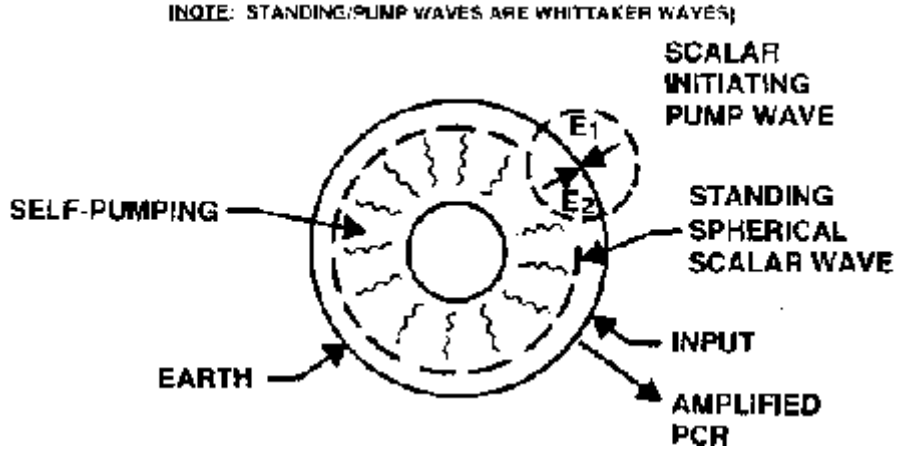


Figure 7. Energy extracted from a single site

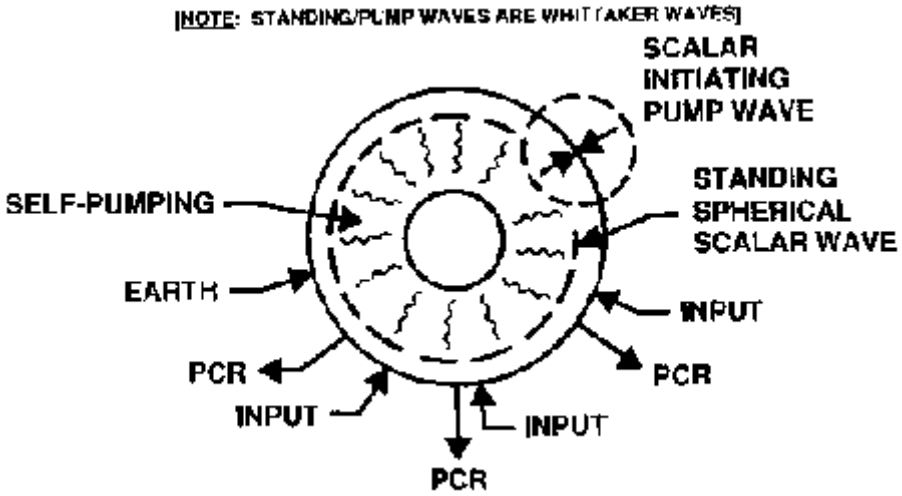


Figure 8. Energy extraction from multiple sites

Corrections for the Real Earth's Departure From the Ideal Model

However, the Earth deviates from an idealized isotropic medium, and its deviations will disrupt the idealized situation so that very appreciable damping of the reciprocal wave occurs, extinguishing the self-pumping feature. Thus large disturbances in and on the Earth - such as explosions, earthquakes, tremors, etc.- cause trembling throughout the Earth, but do not normally result in 4-wave mixing amplification of the effect since the r-waves they temporarily initiate are severely damped.

Accordingly, the idealized scheme as previously described will not work without modification to offset the Earth's deviation from isotropy. Without modification of the technique, the coherent phase-locking of the k-wave and t-wave will be broken, and the reciprocating wave will be sharply damped and will not form a standing wave in the Earth. Consequently, random in-phase occurrences of opposing mechanical stress "tremor frequencies" and opposing heat "EM" stress waves will not "feed-in" to an established standing k-wave, for there will be none established to receive such inputs.

The major problem, then, is to establish in the Earth the standing EM wave of our frequency choice and a standing, phase-locked mechanical wave in phase with it, so that a standing k-wave and canonical standing t-wave - and hence a standing reciprocating wave - are established in the Earth's sphere.

So let us consider why a wave breaks up in a nonlinear medium.

The "breaking phase-lock" problem exists because the speed of a wave in a material medium depends not only on the medium's characteristics but also at least somewhat upon wave's amplitude. Hence, for a sine wave, the peaks travel faster than the lower parts of the wave, overtaking them and causing destructive interference, with consequent wave breakup and severe damping.

This exact problem has been met and successfully overcome with ultrasonic sound waves in the ocean (14). We shall apply the same technique to overcome our breakup and de-phasing problem.

A remarkable phenomenon occurs if two sine waves, separated by a delta frequency, are simultaneously transmitted into the Earth (the real nonlinear medium). In this case, we really wish to utilize the difference frequency between the 2 waves, and pretend that we have transmitted a single sine wave into the Earth at that beat frequency.

It has been shown mathematically that the difference frequency will be propagated through the nonlinear medium as a sine wave, and will not be subject to breakup and damping. We shall refer to this scheme of dual interference frequencies and the resulting beat (difference) frequency as triad usage. With this scheme, we can transmit two waves a fixed frequency apart, and later extract and use the beat frequency as if it were a single sine wave not subject to damping and breakup.

Accordingly, we modify our original transmission scheme and include triad usage. We transmit two frequencies into the Earth a fixed frequency apart. The difference frequency then will first form a standing EM scalar wave, and then our standing in-phase mechanical scalar wave, so that the two together constitute the desired standing k-wave.

From the characteristics of the fundamental quantum, nature itself then forms the phase-locked standing t-wave in inverse phase, completing a standing reciprocating wave in the real Earth.

Extracting Power From the K-Resonant Earth

We now modify our distant "tapping" station transceiver to incorporate triad usage. Again, twin frequencies with the proper separation frequency are transmitted at small power into the Earth as the "input". Twin-tuned LC oscillatory receivers are utilized and their outputs beat together as a beat frequency oscillator. The highly amplified beat frequency (the phase conjugate replica response wave from the self-pumped Earth phase conjugate mirror) is extracted as a sine wave and fed to the transmission lines connecting to the processing station.

A convenient beat frequency, for example, might be 12,000 Hz, and the two transmission frequencies might be 500,000 Hz and 512,000 Hz.

At the receiver, the beat frequency oscillator puts out 12,000 Hz, at very high voltage and amperage. The voltage may be adjusted by biasing the ground potential of one of the LC oscillators in the two that are beat together. The voltage and amperage received from the Earth are varied by adjusting the transmitted voltage and amperage. Standard feedback control techniques are used to provide stability of the output power.

At the processing station, the frequency is stepped down to standard 60 Hz power frequency, and the voltage is stepped down to a convenient high voltage transmission line voltage. To the transmission line leading to the power grid, the processing station appears as any other power station.

Since the Earth is spherical, the oscillation (90-degree) condition for the pumped phase conjugate Earth mirror exists at every point on the Earth's surface.

Therefore additional power stations can readily be added to extract additional power from the same standing r-wave in the Earth's core, without increasing the amount of power input at the activation transmitter site, and without adding any additional activation transmitters. All other transceiver sites will automatically be in oscillation condition for very high gain, so that great power can be extracted from each site. Only a very small transmitted input triad signal need be utilized at each of these additional Earth power extraction stations. Figure 8 shows the case for multiple-site energy extraction.

A single activation transmitter and a single triad transmission creates a single channel (beat frequency) which can be tapped by a large number of separated power extraction stations. Together the triad activation station, single triad beat frequency transmission channel, and multiple power extraction stations on that channel constitute a single channel power distribution system.

Multiple single channel power distribution systems may be established as desired, but one triad activation transmitter is required for each one (15).

Using these principles for portable power units and other systems

We now extend our discussion to point out that the vacuum itself is filled with powerful virtual energy fluxes, penetrating each and every point in space. The particles in the nucleus of every atom. of physical matter are in constant and violent flux exchange with the vacuum, according to modern physics.

Accordingly, a proper nonlinear isotropic model of the Earth - using a mixture of materials such as normally comprise amorphous semi-conductors - can conceivably be made to work in the same

fashion so as to extract energy directly from the vacuum flux (ether). The basic "model Earth" may be simply smoothly pressed pellet of material in external appearance (16).

The "pumping" of the model may be accomplished by placing it under very strong static pressure, such as by special hydraulic means (17). An alternate method is to press and sinter the proper mix of nonlinear materials under very heavy pressure, so that locked-in stresses remain in the fine grains of the amorphous aggregate after the pressed material is removed from the press (18).

A signal input to the stressed "model Earth" medium may be made either electrically through an implanted electrode, by magnetic resonance if ceramic magnetic material is included in the stressed model, by sound, by pulsed infrared frequencies, or any other convenient method. In each case, an amplified phase conjugate replica of the input signal can conceivably be obtained, for the proper conditions and the proper resonant input frequency (19).

It is also conceivable that materials and assemblies can be found which will function to establish themselves as self-pumping PCM triodes in the presence of even small heat and pressure differentials in the local environment. If so, then tiny "triad usage" grid signals to the devices would directly "scavenge" the disordered heat energy and stress energy continually appearing in the environment. Such units would be negentropic, as previously pointed out.

The present author has performed consulting work on one device which utilizes sound to convert the human body to a PPCM-triode and applies "triad-usage" grid input sound signals to "scavenge" long-term, locked-in physical stress from the body, radiating the stress energy away as PCR sound energy. The device is safe and self-regulated, since only excess stress is scavenged and ejected. (Technical details cannot be given because of non-disclosure agreement.)

A great number of other applications for these new effects also exist. For example, there is no discernible reason why inertial strata and material composition of the Earth cannot be determined by analysis of the PCR spectra received from the SPPCM Earth in response to triad-usage stimuli. In this way geolocations of scarce minerals, petroleum, etc., could be readily and accurately determined.

Use of Circular Polarized Transmission Waves

In addition to a triad usage of the best frequency, another means may be utilized to establish a standing scalar EM wave in the Earth. It has been shown that circular polarized waves have standing wave solutions in an isotropic nonlinear medium, while plane polarized waves do not (20). Thus circularly polarized energy offers a means of accomplishing the same end.

In the real Earth, the use of both the circular polarized wave and triad usage is probably advisable, since the Earth medium is not precisely isotropic. Use of both methods simultaneously would appear to minimize the effects of the anisotropic Earth and yield the greatest obtainable efficiency.

Summary and Conclusions

Using a scalar EM approach, we have presented and discussed a means of producing or creating the following:

1. A standing scalar EM wave resonance in and through the Earth, through the medium of the atomic nuclei of the material comprising the Earth's sphere.

2. A special five-dimensional reciprocating wave where stress energy is oscillated canonically between the four spatial dimensions of Kaluza-Klein 5-space and the time dimension.

3. A special five-dimensional reciprocating wave where both mechanical and electrical energy are phase-locked together, and varied canonically with time oscillation.

4. A physical condition in the Earth so that the Earth itself acts as a self-pumped phase conjugate mirror, with very large self-pumping energy furnished by its internal pressure and heat.

5. A means of directly extracting controlled and variable amounts of electrical energy from the internal heat and pressure energy of the Earth, from one or more distant points, with miniscule input energy at each extraction point to initiate the extraction process.

6. A means of converting the Earth to a self-pumped phase conjugate mirror in a four wave mixing system, so that a very large power gain, much greater than unity, can be achieved in output energy and power versus input energy and power.

7. A mechanism underlying Newton's Third Law of Motion, and a means by which the Third Law can be manipulated to allow the production of a free energy device or a unilateral space translation force without the ejection of mass.

8. A mechanism underlying relativity. The curvature of space-time, and time dilation.

9. Conceptual adaptation of the techniques in principle to provide small, clean, portable power units.

10. A possible explanation for the results for such scientific giants as Nikola Tesla and T. Henry Moray: Tesla in powering the Earth with a single giant magnifying transmitter and Moray in producing the first authenticated and rigorously demonstrated practical, portable, "free-energy" device.

Up to now, scalar EM has attracted only scant attention from the scientific establishment in the Western world, even though the well-known "pump wave" in four-wave mixing is a scalar EM (electrogravitational) mechanism that makes possible the pumped phase conjugate mirror amplification of time-reversed EM waves.

Western scientists still have not grasped the great potential of scalar EM to utilize the phase conjugate replica, time-reversed waves, and vacuum structuring to achieve antigravity electromagnetically, engineer the nucleus of the atom in a controlled fashion, produce a unilateral thrust for propulsion without ejection of mass, directly tap and use the boundless energy of the universal vacuum, control and cure diseases electromagnetically, reverse the aging process, and rid the world of chemical, nuclear, electromagnetic and sonic pollution by our present industries and power systems (21).

Nature has been most kind. It appears that she has no immutable laws, for any natural law is subject to change if one can discover her higher methodology beyond the assumed limitations posed by that law.

Let us hasten to apply the new scalar electromagnetic principles to secure a fuller, healthier, more prosperous life for everyone, with liberty, justice, energy, transportation and health for all.

NOTES AND REFERENCES

1. In general relativity, time stress is particularly important in producing space-time curvature, since time is "denser" than length by a factor of c. We desire to form a local curvature of space-time in such a manner as to provide a local source of EM energy. Thus it is imperative to produce a wave of stress in and on time.

2. Since the Earth's internal pressure can furnish energy into (i.e., pump) the mirror during the mechanical (3-space) stress phase of the standing wave, and the zero-multiplied (modulated) zero-vector resultant heat energy components can pump the mirror during the EM (5th dimensional) stress phase of the standing wave. For a comprehensive introduction to standard 4-space phase conjugation and pumped PCMs, see David M. Pepper, "Nonlinear Optical Phase Conjugation," Optical Engineering, 21 (2), Mar./Apr. 1982, pp. 156-183. See also B. Ya Zeldovich et al, Principles of Phase Conjugation, vol. 42, Springer Series in Optical Sciences, Theodor Tamir, Ed., Springer-Verlag, New York, 1985. See also Ammon Yariv, Optical Electronics, Third Edition, Holt, Rinehart and Winston, New York, 1985. See particularly Chapter 16: "Phase Conjugate Optics - Theory and Applications." For examples of laboratory-demonstrated self-pumping, see J.O. White

et al, "Coherent Oscillation by Self-Induced Gratings in the Photorefractive Crystal BI_{12} SiO_{20} (BSO) crystals," Appl. Phys. Lett., vol. 5, 1980, p.102; Mary J. Miller et al, "Time Response of a Cerium-Doped Sr0.75 Ba0.25 Nb_2O_6 Self-Pumped Phase-Conjugate Mirror," Opt. Lett., 12 (5), May 1987, pp. 340-342; Mark Cronin-Golomb et al, "Passive (Self-Pumped) Phase Conjugate Mirror: Theoretical and Experimental Investigation," Appl. Phys. Lett., 41 (8) Oct. 15, 1982, pp. 689-691.

3. For an introduction to 4-wave mixing theory, see Pepper, ibid; Zeldovich. ibid; Yariv, ibid.

4. Per 4-wave mixing theory analogy, the distant transmitter inputs wave A4. The stress energy of the Earth inputs opposing waves A1 and A2, which collectively are referred to as the "pump wave". The nonlinear medium then produces a powerful A3 phase conjugate replica wave, which in a perfect case could contain as much power as is contained in pump waves A1 and A2. In the real Earth there is an efficiency factor for the process which must be determined by experiment.

5. Given that the self-pumping effect is attained successfully. The present author believes that conversion of the Earth to a self-pumped phase conjugate mirror was the secret of Nikola Tesla's magnifying transmitter.

6. In and around May Day, 1985 the Soviet Union conducted a giant, world-wide strategic exercise, powered by multiple such power extraction taps into the Earth. At the height of the exercise Frank Golden - who appears to be the only Westerner who presently can make such scalar EM measurements - measured and placed on the oscilloscope a total of 27 such power channels, each utilizing a pair of frequencies separated by 12 kHz. The author still recalls the feeling of absolute awe that came over him when he realized that beneath his feet, the entire Earth was in entrained giant electrogravitational resonance on 54 different frequencies, captured and held tightly in the grasp of the Soviet Union.

7. For an introduction to the theory of time-reversed EM waves, optical conjugation, pumped phase conjugate mirrors, see Pepper, ibid; Zeldovich. ibid. See also Robert A. Fisher, Editor, "Optical Phase Conjugation", Academic Press, New York, 1983. For a more general discussion of the importance of time reversal to quantum mechanics and other aspects of modern physics, see Robert C. Sachs, 'the Physics of Time Reversal", University of Chicago Press, Chicago, 1987.

Other interpretations of time-reversed electromagnetics are also possible. For an interesting and quite different adjunct type of time-reversed EM - one similar to the thinking of the present author - see Shiuji Inomata, "Consciousness and Complex Electromagnetic Fields", Electrotechnical Laboratory, 5-4-1 Mukodai-cho, Tanashi-City, Tokyo, Japan, 1976. Inomata adds a complex magnetic field to Maxwell's equations, restoring their symmetry. He does this by introducing an imaginary magnetic current and an imaginary magnetic charge. Both the electric and magnetic fields now are complex; each is the sum of a real component and an imaginary component. An equation then results for the new imaginary or "shadow" EM in which: (1) the roles of electricity and magnetism are inverted, (2) time is reversed, (3) every electronic charge is accompanied by a shadow monopole, (4) every electronic current coexists with a shadow magnetic current, (5) for the shadow current, everything is transparent, (6) negative energy is fed from an infinity point as an "advanced wave" in acausal and "action-at-a-distance" fashion, and (7) by using shadow electromagnetics and negative energy, "free energy" and negentropic devices are possible.

It should also be realized that the real nature of a photon vis-is an EM wave, has not been resolved in physics. A view in agreement with my own that, for a monochromatic EM wave, a single wave cycle constitutes a photon, is presented by Robert L. Wadlinger, "What Does E = hv mean?", Speculations in Science and Technology, I (5), 1978, p. 469-476. See also W.M. Honig, Found. Phys. 4, 1974, p. 367-380; Found. Phys. 6, 1976, p. 37-57 and p. 46-49; Int. Jour. Theor. Phys. 15, 1976, p.673-676. The concept of the single cycle as the simplest photon may be closely related to the solitary wave (solition) concept introduced by Scott-Russell in 1844; see B.C. Scott et al, Proc. IEEE 61, 1973, pp. 14431482. Such solitions exist as discontinuous solutions of many of the wave equations in physics. I personally view a modulated wave and a complex wavefront as having created a "giant photon" of complex shape, containing a specific substructure. From the quantum

mechanical idea that a photon is a virtual electron/positron pair, I also view one part of the giant photon as carrying or containing positive-charge/negative-time, and the other part of the giant photon as carrying or containing negative-charge/positive time. In this view, I consider the photon in vacuum as a deterministic structure in the vacuum's EM potentials, and refer to such structured photons as "vacuum engines". The "coupling together by modulation" of such a giant photon with its phase conjugate replica provides a "scalar vacuum engine," one which converts all its EM stress energy into gravitational stress of time. It is thus a "time-stress engine" of purely electrogravitational nature.

The scalar vacuum engine contains a stabilized, dynamic, deterministic pattern impressed in and on the local curvature of space-time. This type of vacuum engine - even one of miniscule power - passes through the electron shells of an atom and interacts directly within the atomic nucleus. Continual irradiation of the atomic nucleus with a specifically patterned scalar vacuum engine gradually "charges up" the nuclear potential with that specific engine's charge pattern or substructure. By producing the desired potential substructure in the atomic nucleus, the structure of the nucleus itself can be altered and directly "engineered" in controlled fashion, rather than just being bluntly struck with a particle hammer as in normal high-energy physics.

8. This point has previously been well-covered by the author. For example, see Bearden, "Extraordinary Physics", AIDS: Biological Warfare, Tesla Book Co., POB 1649, Greenville, Texas 75401, 1988, p. 74-203.

9. Regard "closure of a system" as essentially a statement of a locally flat space-time, and a linear statement of Newton's Third Law. On the other hand, if the local space-time is curved, then Newton's Linear Third Law need not apply because in this case the system is opened and can exhibit "hidden source" and "hidden sink" effects. If we control the local curvature and vacuum structuring, we can control and change the magnitude and direction of Newton's Third Law reaction force. Creation and use of structured potentials with macroscopic deterministic substructures in the local vacuum is one means of achieving local, deterministic space-time curvature with directed macroscopic source or sink currents - in effect, this process produces usable "Maxwell's Demons".

For a special kind of "Maxwell's Demon", see Cynthia Kolb Whitney, "Field-to-matter energy transfer", 1988 (to be published). Quoting: "Physicists have always believed that classical field-matter energy exchange is strictly one-way, fields receiving energy and matter losing it, via radiation. That belief is consistent with the accepted formulation for potentials created by relativistically moving sources. But that formulation has recently been shown to embed an error. Correction of the error allows reverse energy transfer, from fields to matter. Though previously unexpected, this mechanism becomes credible by offering a candidate explanation for certain otherwise mysterious natural phenomena. The mechanism behind the reverse energy transfer is relativistic torquing within any interacting multi-body system. The existence of relativistic torquing invites human intervention, to induce controlled energy transfer that can be tapped for human purposes such as propulsion. The design of an engineering system to demonstrate such a function on a laboratory scale is discussed."

For a deeper insight into this fundamental EM mistake that Whitney has discovered - one that has long been made and perpetuated in relativistic potential theory - see Cynthia Kolb Whitney, "Manifest Covariance in Relativistic Potential Theory", Physics Essays, 1(1), 1988, p. 18-19; "Generalized Functions in Relativistic Potential Theory", Hadronic J. 10, 1987, p 91-93; Whitney, "Electromagnetic Fields Near Dynamic Systems of Charged Particles", Hadronic Journal, 10, 1987, p. 299-301.

For an important expose of the importance of zero-point vacuum energy fluctuations and the interaction potential to a naturally-arising "already-unified" field theory, see H.E. Puthoff, "Zero-point Fluctuations of the Vacuum as the Source of Atomic Stability and the Gravitational Interaction", Proceedings, British Society of Science International Conference 'Physical Interpretations of Relativity Theory'", Imperial College, London, Sept. 1988. Puthoff puts it plainly: "Whether addressed simply in terms of Newton's Law, or with the full rigor of general

relativity, gravitational theory is basically descriptive in nature, without revealing the underlying dynamics for that description. As a result, attempts to unify gravity with the other forces (electromagnetic, strong and weak nuclear forces), or to develop a quantum theory of gravity, have foundered again and again on difficulties that can be traced back to a lack of understanding at the fundamental level." Puthoff's paper now points the way directly to the understanding of gravitation at the fundamental level.

My own additional comment is that macroscopically structuring the local vacuum potential by use of scalar vacuum engines (as developed in Note 7 above) accomplishes limited directional structuring of zero-point vacuum fluctuations. By this means the nucleus of the atom can easily be reached and engineered, with milliwatts or even microwatts of input electromagnetic power. By using scalar vacuum engines, one can directly perform electrogravitational engineering. The results may be dramatic, particularly when higher power levels are utilized. For example, John Hutchison of Vancouver utilizes two separated, opposing, violently discharging Tesla coils to provide a 4-wave mixing "scalar pump wave" into a target material or object geometrically between the coils. When conditions are just right, the powerful scalar vacuum engines deposited into the nuclei of the target object create nuclear potentials that have an excess of negative time flux. Since in negative time the gravitation is a repulsive force, levitation of macroscopic objects - some weighing over 60 pounds - have been achieved. The major barrier to the experiments is that presently it uses relatively uncontrolled frequencies. Antigravity (production of excess negative time flux in the atomic nucleus) is largely an extremely low frequency effect, since the lower the energy increment that a photon carries, the greater the time increment it carries. All that is necessary to produce controlled antigravity is to produce a pumped phase conjugate mirror at under, say, 400 Hz. In that case a few hundred watts of pump power is sufficient to levitate one pound of mass. On the other hand, the effect cannot even be detected at optical frequencies, since the energy increment of an optical photon is extremely large and its time increment is extremely small. Pump waves at optical frequencies produce such little excess negative time flow in the atomic nuclei of the pumped phase conjugate mirror that the antigravity effect is essentially immeasurable.

10. This follows immediately since the electrogravitational standing wave represents a stabilized, standing oscillation in the local curvature of space-time. Einstein kept his general relativity in accord with conservation laws only by imposing the severe restriction that local space-time was never curved. For proof that in a curved space-time all conservation laws can be and are violated, see V.I. Denisov and A.A. Logunov, 'the Inertial Mass Defined in the General Theory of Relativity Has No Physical Meaning", Teor. i. Matemat. Fizika, 51 (2), May 1982, p. 163-170 (in Russian); A.A. Vlasov and V.I. Denisov, "Einstein's Formula For Gravitational Radiation is Not a Consequence of the General Theory of Relativity", Teor. i. Matemat. Fizika, 53 (3), Dec. 1982, p. 406418; V.I. Denisov and A.A. Logunov, "New Theory of Space-time and Gravitation", Teor. i. Matemat. Fizika, 50 (1), July 1982, pp. 3-76. Quoting Denisov: "... in general relativity there are no energy-momentum conservation laws for a system consisting of matter and the gravitational field... The gravitational field in general relativity is completely different from other physical fields, and is not a field in the spirit of Faraday and Maxwell."

Whitney has also identified a completely new process for accelerated systems: the reverse transfer of energy from field to matter, using the mechanism of relativistic torquing within any interacting multi-body system. Since this mechanism moves energy from fields to particle orbits (Whitney, "Equations of Motion for the Gravitational Two-Body Problem", Hadronic J. (in publication), controlled interventions by humans is suggested - for example, to alternate between a relativistic torquing state to excite orbital particles from the background field, and a non-torquing state where the excited orbital particle decays, releasing ordinary energy externally for use. See Cynthia Kolb Whitney, "Field-to-Matter Energy Transfer". The combined dual process might provide a sort of "one-way gate valve" to gate energy from background fields to external loads - a special kind of "Maxwell's demon".

Also, nonlinear effects can result in increased localized absorption effects in small particulate matter. The "extra energy density" is extracted from localized regions of virtual particle flux (vacuum charge), and the vacuum simply replenishes itself from regions outside that locality. See

H. Paul and R. Fischer, "Comment on 'How Can a Particle Absorb More Than the Light Incident on It?'", American Journal of Physics, 51 (4), Apr. 1983, p. 327.

11. A local space-time curvature in one direction yields a hidden local source in the vacuum itself (curvature in the opposite sense would yield a hidden sink). This vacuum energy hidden source can conceivably be tapped to produce useful energy. If so, since the disintegrated energy of vacuum would be the source, such a device would most probably produce negative energy consisting of phase-conjugated or time-reversed EM waves. (See C.W. Rietdijk, "How Do 'Virtual' photons and Mesons Transmit Forces Between Charged Particles and Nucleons?", Foundations of Physics, 7 (5-6), June 1977, p. 351-374. As pointed out by Rietdijk, virtual photons and mesons transmitting coulomb and nuclear forces do not arise from temporary violations of energy conservation, as commonly accepted. They involve negative energy transmission, and traveling backward in time.) Circuits in purported prototype "vacuum energy tapping" devices (which in their mechanisms ultimately deal with extraction from the atomic nucleus) built by Moray, Bedini, Nelson et al, are reputed to "run cool", suggestive of a negative energy effect.

Indeed, the present author's own theory of ball lightning is that counterbalancing negative and positive energy radiation interactions are simultaneously and abruptly produced by enmeshed, multiple 4-wave mixing in a local region of air in a lightning strike or potential discharge. Multiple "EM stress waves" caused by multiple forks, etc. of the lightning strike/discharge are generated in a local nonlinear region of the air, to form a swirling plasma. When formative conditions are just so, this highly nonlinear plasma together with the "EM stress waves" becomes a pumped phase conjugate mirror ensemble. Other external input EM forks from all directions into each part of this mirror ensemble result in release of phase conjugate (time reversed) replicas from each portion (submirror), radially outbound and containing negative energy. The outbound negative energy in turn constitutes inputs to the pumped phase conjugate mirror plasma and to each contacted submirror, generating time-reversed, amplified radially inbound energy. Reverberation and adjustment back and forth between the 2 modes results in an equilibrium between outbound (negative) and inbound (positive) energy states. When the configuration is disrupted sufficiently by anisotropic leakage or physical contact, the mirror ensemble effect is ruptured in the explosive dissipation from the ball/mirror ensemble of its entrapped energy.

12. See Pepper, ibid.; Yariv, ibid.; Fisher, ibid.; Zeldovich. ibid. for discussions of 4-wave mixing, pumped phase conjugate mirrors, and nonlinear power reflection coefficients (i.e., gain).

13. See Amnon Yariv, ibid., p. 510 for a plot showing the nonlinear power reflection coefficient's rise to infinite gain at the oscillation condition. It is stressed that "infinite gain" means that the device can extract and get out in the PCR - up to all the available energy with which it is being pumped (assuming a 100% efficient device). A 100% efficient device literally "scavenges up, orders, and transmits out" all available pumping energy. That is, in one sense it can scavenge out and radiate away all stress encountered, - even if the stress's force components are disordered - if that stress acts as a pump.

Note especially that this effects offers a general and universal mechanism to freely tap energy from any source of continuing stress, whether the stress is due to magnetic force fields, magnetostatics, hydraulic pressure, mechanical stress, gas or fluid pressure, electrical force fields, electrostatics, etc. Quantum mechanically, all stress component are (at base level) electromagnetic in nature, even though the basic stress is due to virtual particle (e.g., virtual photon) exchange. Each of these virtual particle streams is fluctuating and dithering, and so can act as a "pump wave's to the proper PCM material. The stress source (e.g., opposing north poles of a permanent magnet) and the proper nonlinear PCM material will constitute a PPCM. All that is necessary is: (1) find a material and conditions for the oscillation condition, so that over-unity gain can be realized, (2) furnish the small "grid" input (input A4 in standard 4-wave mixing theory), (3) receive, collect and distribute to the load the concomitant amplified PCR energy. From this viewpoint, Tesla's magnifying transmitter concept actually utilizes a universal "free-energy" mechanism, and one where the existence of the basic "self-pumping" and "self-organizing" phenomena is now well-established in nonlinear optics.

14. Owen Flynn, "Parametric Arrays: A New Concept For Sonar", Electronic Warfare Magazine, June 1977, p. 107-112. Any two sine-wave frequencies as simultaneous drivers combine to produce a sine-wave difference frequency propagating in water, essentially without sidebands or reverberations. Its pattern has a main lobe approximately equal to that of the high frequency drive, but devoid of sidelobes. The level of the propagating difference frequency is proportional to both the product of the two fundamental drive levels and to the square of the desired value of difference frequency. An experimental parametric array was built by Westinghouse Electric Corp., Baltimore, for the Naval Underwater Systems Center, New London, Connecticut. Though derived for ultrasonic waves in oceanic medium, the mathematics is general. It applies to the wave equation and hence to electromagnetic waves as well.

15. Apparently the Soviets have already developed and tested such multiple-channel "Earth power" systems, and used them to power a series of giant strategic scalar EM weapons. See note 6, above. Powering such weapon complexes from local power taps into the Earth itself would provide a major advantage in case of nuclear war, where the wholesale disruption of normal systems by, say, giant electromagnetic pulses from high nuclear bursts of large yield, is almost a certainty.

16. Significantly, T.H. Moray used just such internally stressed pellets of nonlinear material in his well-documented energy device which reportedly produced 50,000 watts of power from a 55-pound device. He also incorporated a radioactive material so that a convenient "decay channel" existed in the virtual (potential) state of the vacuum flux, as a sort of "one-way railroad" from the nucleus to the external, macroscopic world outside the atom. See T.H. Moray, "The Sea of Energy", 5th Edition, History and biography by John E. Moray. Foreword by Thomas E. Bearden, Cosray Research Institute, 2505 South 4th East, Salt Lake City, Utah 84115, 1978 for details of the Moray device and its testing.

17. On one occasion known to the present author, a company engaged in pressing pellets of nonlinear material (with ingredients similar to the Moray pellet constituents) to very high pressure (i.e., to pressures of artificial diamond magnitude) encountered a very strange accident. During the intense part of the pressing operation, a giant, brilliant flash suddenly erupted from the mold, and a surge of thousands of amperes from the pellet materials destroyed the electrical system of the press and other nearby equipment.

18. T.H. Moray pressed his pellets in large railroad presses, achieving as much locked-in stress in his powdered pellet materials as possible. A sort of sintering process also seems to have been utilized by Moray, to "lock-in" stresses in the grains of his pellets.

19. Note that at radar frequencies, radar-absorbing materials vastly slow the travel of an entering EM radar wave. With special nonlinear RAM-type materials and multi-beam radiation, therefore, standing scalar EM waves can be obtained in materials of small size, simply by applying the pump concept. Theoretically, portable power units using the principles stated in this present paper can be small, and need not involve unduly large and bulky equipment.

We also accent that, at the quantum level, often a particle may already absorb more energy than is incident upon it, simply by taking extra energy from the local vacuum flux (which, in our opinion, acts as a "pump" for the charged particle in this case, converting the particle into a PPCM). For example, see Craig F. Bohren, "How can a particle absorb more than the light incident on it?", Am. J. Physics, 51 (4), Apr. 1983, p. 323-7. Also: H. Paul and R. Fischer, "Comments on 'How can a particle... ', Am. J. Phys., 51 (4), p. 327. Note that changes in effective absorption cross sections may actually be the result of the changing degree of operation of the particle/field or the macroscopic object/field as a PPCM.

20. The circular polarization standing wave closed solution in isotropic nonlinear media is well-known in Soviet literature (see A. Ya. Terletskii, "Some exact wave solutions of nonlinear electromagnetic field equations", Dokl. Akad. Nauk. SSR., 19 (6), 1974, p. 344-5. The standing wave solutions of circularly polarized waves in an isotropic nonlinear medium are, non-sinusoidal in form).

21. For possibilities - good and bad - posed by scalar EM and TR wave applications see Bearden," Fer-de-Lance", Tesla Book Co., 1986; "AIDS: Biological Warfare", Tesla Book Co., 1988; "Soviet Phase Conjugate Weapons: Weapons that use time-reversed electromagnetic waves", Bulletin, CRCC, Ft. Collins, CO. Jan. 1988.

The distribution of electrical power by means of terrestrial cavity resonator modes

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The Earth-Ionosphere cavity can be used as a means to distribute electrical energy for industrial purposes at extremely low frequencies. The technology which will permit the wireless distribution of electrical power to or from remote geographical regions is now available for research and development.

It is advanced that the Earth-Ionosphere cavity possesses electrical properties which are appropriate for the wireless distribution of electrical energy to any point on Earth on an industrial scale. Such a remarkable proposition, though seemingly a fanciful concept, is actually no more profound than the notion advanced in the early 1950's to use a cavity resonator to wirelessly distribute microwave power to process food, i.e. - a microwave oven.

Electrical energy at the appropriate frequency may be introduced at one point in a cavity resonator and efficiently collected at another by devices tuned to the same frequency. The resonator itself serves as a two port reactive distribution system. The ELF (extremely low frequency) resonator formed by the cavity between the Earth and the lower E-region of the ionosphere is a nature! resource, that will actually permit the terrestrial distribution of electrical power across a continent, without the necessity of an interconnecting land-line grid of high tension transmission lines.

History

From an historical standpoint, it is significant that Nikola Tesla long ago envisaged such a global power distribution system. A flag of caution should be raised here. It has been common in the past to discard Tesla's far-sighted vision as baseless. We believe that such depreciation has stemmed from critics who were, in fact, uninformed as to Tesla's techniques, measurements and physical observations. After reviewing Tesla's technical disclosures, it is our considered judgement that not only is industrial scale power transmission practical, but that Tesla's actual data is consistent with the very best experimental data available today. It could have only been gotten as a result of authentic terrestrial resonance and power transmission measurements.

Tesla proposed that the Earth itself could be set into a resonant mode at frequencies on the order of 7.5 Hz. From his notes, his private correspondence, his diary and his patent disclosures, it is clear that Tesla's physical explanation and interpretations were erroneous. However, as is often the case, significant explorations or inventions have been made on the basis of faulty physical concepts. Experiments were done, demonstrations performed and data taken. Let us review some of the history behind this early research.

Tesla's ELF enterprise

In May of 1899, Tesla arrived at Colorado Springs, Colorado with $100,000. This is the same Tesla whose patented AC power system, purchased by the Westinghouse Corporation which was selected and installed in the original Niagara Falls electric power project of the 1890's. Perhaps it is not unremarkable that almost a century later most of the civilized world still employs a power generation and distribution system in virtually the same form as his early disclosures.

Within three months of his arrival at Colorado Springs, he and his associates constructed a laboratory which housed a prodigious RF signal generator. The primary and secondary were wound on a circular fence 51 feet in diameter and had an input power in excess of 250 KW provided by the Colorado Springs Electric Power Company. The secondary was used to drive a helical resonator, or extra coil, 10 feet high, wound with 100 turns of c6 gauge wire on a coil form about 8 feet in diameter. Emanating from the midst of the extra coil was a tower about 150 feet high, capped with a copper sphere 3 feet in diameter. The resonant frequencies of the driving transmitter have been variously reported as between 50 KHz to 150 KHz. This transmitter, we believe, was used as one component in a recently uncovered process to produce significant currents in the vertical tower and its attachments at pulse frequencies of 7.5 Hz to 15 KHz.

A very colourful account of the first time Tesla fired up his equipment is given in O'Neill's now classic, though somewhat unreliable, biography. Tesla, on various occasions actually said that he had created sparks 150 feet in length. His experiments in Colorado Springs lasted nine months and cost in excess of $200,000.

Tesla returned to New York on January 21, 1900 and soon received the financial backing of J.P. Morgan, Thomas Fortune Ryan, John Jacob Astor and others. His patent application of January 18, 1902 reveals his intention to construct a massive Tesla coil driven generator for global power distribution.

The installation was subsequently constructed at Wardenclyffe, Long Island in 1902. The tower was 154 feet tall and the cap sphere was 50 feet in diameter. It was never completed, however, and was destroyed during WW 1. Similar towers were to have been built at Niagara Falls, in Australia and in Europe. Tesla, however, had to abandon the Wardenclyffe project when his financial backers withdrew their support.

Physical Operation

Tesla had proposed that the Earth itself could be set into resonant electrical oscillations which he experimentally determined to be no lower than 6 Hz and no greater than 20 KHz. He claimed to have resonated the Earth in this frequency range by using a huge spark gap transmitter energized by the standard secondary of his monstrous Tesla Coil. His patent application of February 19, 1900, entitled "Apparatus for Transmission of Electrical Energy" is probably the closest description available of the equipment used at Colorado Springs the previous summer. Assuming Tesla's claimed demonstration of distant power transmission without wires as a working hypothesis, then a plausible physical explanation is that the discharges from the electrode at the top of his giant tower would have significant spectral components at the Schumann resonance frequencies and excite a standing wave mode in the Earth-Ionosphere cavity. These physical issues have been addressed in recently presented technical publications. The overwhelming documented technical evidence clearly substantiates the above position.

Schumann Resonances

In 1952, the German physicist, W. O. Schumann recognized the possibility that a somewhat unusual example of a resonant cavity might be provided by the Earth itself as one boundary surface, and the ionosphere as the other. These two concentric spheres could then form the boundaries of a resonant electromagnetic cavity. (Sea water has a conductivity of 4 Siemens/meter while the ionosphere has an effective conductivity on the order of 1 milli-Siemen/m. Evidently, the structure can easily support damped oscillations.)

Determination of the cavity resonant frequencies follows from a solution of Maxwell's Equations subject to the given boundary conditions. At extremely low frequencies (ELF), where the wavelength is large compared to the effective height of the ionosphere, the electric field is essentially radial, and its amplitude distribution varies as the cosine of the polar angle measured from the position of the source antenna. Amplitude distributions for the first and second modes of oscillation of the Schumann cavity are as shown in Figure 1, when the Earth-Ionosphere cavity is excited by a source which launches vertically polarized electromagnetic waves from the North Pole.

Measured Electrical Properties

There are a variety of electrical properties of the Earth-Ionosphere cavity which have been experimentally determined over the past twenty years and are now well documented in scientific literature.

(a) Spectral Response

The resonant frequencies of the cavity have been predicted and observed. One would expect natural phenomena to excite cavity oscillations. This, indeed, does happen. The cavity is set into oscillation by solar flares, for example. But, by far the dominant natural phenomenon exciting cavity resonances is thunderstorm activity occurring world-wide. The power density spectrum of a lightning stroke is very broad, containing a wide band of frequencies. Electrically, the Earth-Ionosphere cavity behaves like a multiply tuned LC network driven by an impulse generator, and oscillations are excited at the natural resonant frequencies of the network. Thunderstorm activity is more or less continuously present on Earth, with the main centers of activity being Southeast Asia, the Congo and the Amazon Basin. Consequently, experimental measurements of the atmospheric noise power density spectrum would be expected to reveal peaks at the cavity resonant frequencies, should Schumann's hypothesis be correct. Figure 2 is a typical measurement of the atmospheric noise spectral density vs. frequency. The first few cavity resonances reported above are quite evident. This is how the measured values were determined.

These sorts of measurements have been reported by many observers over the past 20 years. The spectra are frequently skewed about the center frequency and may undergo variations up to about 1 Hz in periods on the order of a minute or so.

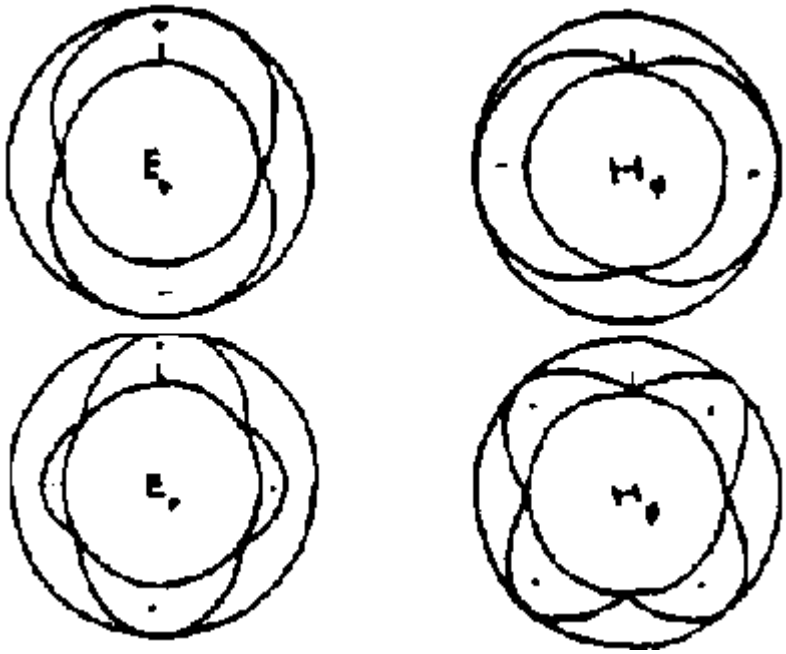

Figure 1. Radial electric field E_r and azimuthal magnetic field intensity He, for the first two cavity resonator modes of the Earth-Ionosphere shell.

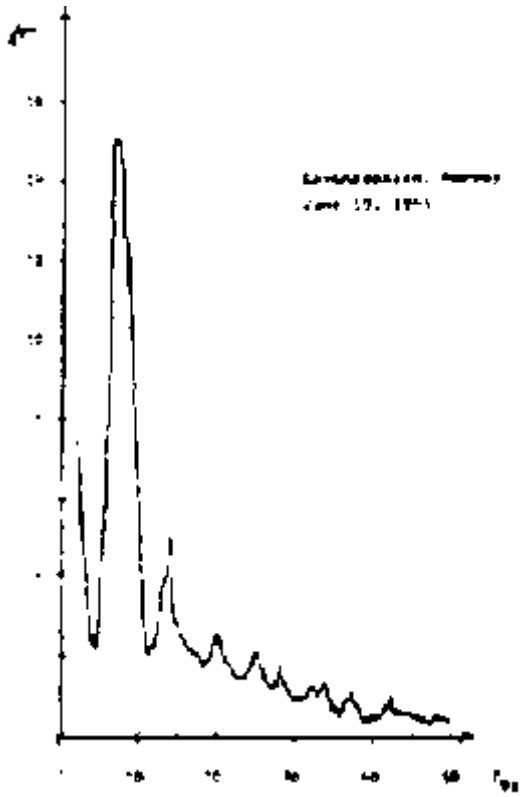

Figure 2. Typical spectrum of cavity noise. Prominent Schumann resonances at 8, 14, 20 and 26 Hz are visible. Peaks at 32, 37 and 43 Hz are apparent.

(b) Cavity Q

An important practical question associated with the Earth-Ionosphere cavity is its ability to store or contain energy without dissipating it by heating up the Earth or the ionosphere boundaries. In electrical and microwave circuit theory, a quantity called the Q of the resonant cavity is determined as a ratio between the stored energy and the energy loss per cycle in the cavity,

$$Q = \omega_0 \frac{\text{stored energy}}{\text{power lost}}$$

where ω_0 is the resonant angular frequency assuming no losses. The Earth-Ionosphere cavity Q has been measured and documented experimental data places it in the range between 3.8 to 7.8.

(c) Propagation Attenuation Constant

While the above Q is relatively low for a tuned circuit, it does indicate that the waveguide propagation losses are surprisingly small. For electromagnetic propagation on a transmission line or in a waveguide, a forward traveling wave attenuates as

$$E(\ell) - E_0 e^{-\alpha \ell}$$

where α is the attenuation constant in nepers per meter. The measured value of the attenuation constant for ELF waves propagating in the Earth-Ionosphere cavity has been experimentally determined to be on the order of one quarter of a dB per thousand kilometers. By way of comparison, single circuit 200 KV 60 Hz overhead power transmission lines have attenuation constants on the order of 1.15 dB per thousand kilometers. Experimentally established transmission and distribution losses are 23% less for the Schumann Cavity than for conventional power transmission lines.

The issue of the practicality of the proposed distribution system does not rest upon the efficiency of the transmission medium. Rather, the technical issue to be faced concerns the electromagnetic coupling mechanism to be used. This issue, we believe, was addressed by Tesla and the experimental results which he disclosed testify to his conspicuous success

The Earth-Ionosphere cavity is, indeed, capable of being artificially excited into oscillation and the cavity can be employed as a medium for the global distribution of electrical power.

What is required is the creation of a practical engineering capability to efficiently launch electrical power into the cavity and to couple energy from the cavity.

It is absolutely astonishing that Tesla's public disclosures and technical publications match the electrical properties of the Schumann Cavity fifty years before there was even a theoretical model to predict rough values.

The conclusion should be obvious: Tesla could have only obtained these numbers by successfully stimulating the cavity. Tesla had to have solved the problem of launching energy into the Earth-Ionosphere waveguide and coupling energy from the cavity. We believe that the technical aspects of his apparatus have been sufficiently disclosed, in his patents, to be able to replicate his cavity stimulation and power transmission experiments. This experimental investigation should be carried out immediately. Clearly, whoever executes a sound and careful program of research along these lines will develop a technology capable of distributing electrical energy on a vast scale without the necessity of a land-line network.

It is evident that we are advocating one of the most visionary energy distribution systems ever conceived. And yet we maintain that it is technically sound and can be swiftly inaugurated at a fraction of the capital investment required by the only other alternative electrical power distribution system - high voltage overhead power transmission lines.

Tesla was aware of this and could clearly see through to the logical conclusion. When he returned to New York City in 1900, he wrote:

"Men could settle down everywhere, fertilize and irrigate the soil with little effort, and convert barren deserts into gardens, and thus the entire globe could be transformed and made fitter abode for mankind."

This program will inevitably have an even broader impact upon all the civilized world. The electrical power industry will experience a major innovation. The global economics of today, which is so petroleum dominated, would be transformed overnight to reflect the importance of those nations which are happily endowed with natural resources appropriate for the generation of electrical energy.

Such research will not only revolutionize the areas of energy, transportation, agriculture and commerce, but, in all probability, could even inspire significant alterations in the present structure of world governing bodies. We are referring to the consequences initiated by a. global diffusion of energy. International society could perhaps be on the verge of a metamorphosis comparable in magnitude to the great agitation, evolution and achievement which so characterized the European Renaissance and the forward progress of civilization to which it gave birth.

During the last century, natural science seemed, for all intents and purposes, to have reached its maturity. From our vantage point today, that period is called 'the Golden Age of Classical Physics". Yet, almost a hundred years ago, remarkable discoveries began to be made which would engender profound modifications of classical physics. It was the experimental science of the 1890's which would soon give birth to what, today, we call modern physics. It was a renaissance no less than the transition which had occurred several centuries earlier in art, literature and natural philosophy.

It has been observed that, standing on the threshold of the 1890's, only a writer of science fiction could have dreamed of the revolution on physical thought which was to occur over the next few years. And even the poets and writers of that day were unable to grasp the impact which the new science would soon have on industry, the military and the political life of the entire planet, which we have observed during the twentieth century.

Today, we stand on a similar threshold. But now it is technology which is experiencing such radical growth We submit that the "high tech" society which we enjoy today may be but a destitute and

primitive shadow of the flourishing civilization which could soon emerge across the threshold of the 21st century.

The power distribution system which we are proposing will surely require careful and considered investigation. There are no simple engineering answers.

Engineering has been called "that profession which utilizes the resources of the Earth for the benefit of mankind". We are proposing the initial step in what eventually will be an engineering project the scale of which civilization has never endeavored to attain before. But never since the days of Columbus, could so much be gotten for so small a financial investment. Never before in recorded history has it been within the grasp of the technical community to so dynamically influence the advancement of civilization.

The engineering challenge

There is a need for a practical waveguide probe capable of exciting the Earth-Ionosphere cavity at 8Hz where the wavelength is about 37.5 million meters. Poor radiation efficiency and physical size limitations for such probes in previously known technology have been overcome with our inventions, patented in the U.S. and other nations. (Nos. 4,751,515 and 4,622,558). With these, a contrawound structure waveguide probe of reasonable size can be built which can excite the Earth-Ionosphere cavity. It employs the earth as an image current source and has a maximum dimension of 0.001 free space wavelengths (with much smaller sizes possible), designed to launch vertically polarized, omnidirectional energy efficiently into the cavity at its primary resonant frequency, or sufficiently close to a resonance frequency so as to be within the resonance frequency bandwidth. Because propagation losses are so low at the primary Schumann resonance frequency, signals at that frequency may be transmitted to any point of the earth without significant attenuation.

An important element of the inventions is that the path inhibit propagation, thereby creating slow waves, and provide an electromagnetically closed path so that a standing inhibited-velocity wave, or resonant operation, can be established in response to the flow of electrical current through the path.

One half of the electrically conducting path may be eliminated in embodiments of the structure by employing the image theory technique. Thus, a conducting image surface electrically supplies the missing portion of the path. The image surface may be a conducting sheet, a screen or wires arranged to act electrically as a conducting sheet, or may be the earth, in accordance with the improvement disclosed in the patents of the known electromagnetic theory.

COMPARISON OF PHYSICAL PARAMETERS

Physical Parameter	Accepted Experimental Values	Predicted from Tesla's Disclosures
Attenuation Constant (dB/Mm)	$.20 \leq \alpha \leq .30$	.26
Resonant Frequency (Hz)	$6.8 \leq f_0 \leq 7.8$	6
Cavity Q	$3.8 \leq Q \leq 7.8$	$3.2 \leq Q \leq 6.4$

Coherence Time (sec.)	no data available	0.08484
Phase Velocity	$.71 \leq V_r \leq .83$	0.8
Cavity Mode Structure	$P_n(\cos\theta)$	"Projections of all the stationary nodes onto the earth's diameter are equal."
Cavity Thickness (Km)	$35 \leq h \leq 80$	"greater than 8 Km" "about 20 Km"

Table 1. Documented numerical evidence that Tesla excited terrestrial resonances in 1899. Additionally there is a host of descriptive evidence.

Wireless transmission of power - resonating planet Earth

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Many researchers have speculated on the meaning of the phrase "non-Hertzian waves" as used by Dr. Nikola Tesla. Dr. Tesla first began to use this term in the mid 1890's in order to explain his proposed system of wireless transmission of power. In fact, it was not until the distinction between the method that Heinrich Hertz was using and the system Dr. Tesla had designed, that Dr. Tesla was able to receive the endorsement of the renowned physicist, Lord Kelvin. (1)

To this day, however, there exists a confusion amongst researchers, experimentalists, popular authors and laymen as to the meaning of non-Hertzian waves and the method Dr. Tesla was promoting for the wireless transmission of power. In this paper, the terms pertinent to wireless transmission of power will be explained and the method to be used by present researchers in a recreation of the Colorado Springs experiment will be defined.

Early Theories of Electromagnetic Propagation

In pre-World War I physics, scientists postulated a number of theories to explain the propagation of electromagnetic energy through the ether. There were three popular theories present in the literature of the late 1800's and early 1900's. They were:

1. Transmission through or along the Earth.
2. Propagation as a result of terrestrial resonances.
3. Coupling to the ionosphere using propagation through electrified gases.

We shall concern our examination at this time to the latter two theories as they were both used by Dr. Tesla at various times to explain his system of wireless transmission of power. It should be noted, however, that the first theory was supported by Fritz Lowenstein, the first vice-president of the Institute of Radio Engineers, a man who had the enviable experience of assisting Dr. Tesla during the Colorado Springs experiments of 1899. Lowenstein presented what came to be known as the "gliding wave" theory of electromagnetic radiation and propagation during a 1915 IRE lecture.

Dr. Tesla delivered lectures to the Franklin Institute at Philadelphia in February, 1903, and to the National Electric Light Association St. Louis in March 1903. The theory presented in those lectures proposed that the Earth could be considered as a conducting sphere and that it could support a large electrical charge. Dr. Tesla proposed to disturb the charge distribution on the surface of the Earth and record the period of the resulting oscillations as the charge returned to its state of equilibrium. The problem of a single charged sphere had been analyzed at that time by J.J. Thompson and A.G. Webster in "The Spherical Oscillator." This was the beginning of the science of terrestrial resonances, culminating in the 1950's and 60's with VLF radio engineering and discoveries of W.O. Schumann and J.R. Waite.

The second method of energy propagation proposed by Dr. Tesla was that of the propagation of electrical energy through electrified gases. Dr. Tesla experimented with the use of high frequency RF currents to examine the properties of gases over a wide range of pressures. It was determined by Dr. Tesla that air under a partial vacuum could conduct high frequency electrical currents as well or better than copper wires. If a transmitter could be elevated to a level where the air pressure was on the order of 75 to 130 millimeters in pressure and an excitation of megavolts was applied, it was theorized that;

"... the air will serve as a conductor for the current produced, and the latter will be transmitted through the air with, it may be, even less resistance than through an ordinary copper wire. " (2)

Resonating Planet Earth

Dr. James T. Corum, in chapter two of his soon to be published book, "A Tesla Primer", points out a number of statements made by Dr. Tesla which indicate that he was using resonator fields and transmission line modes:

1. When he speaks of tuning his apparatus until Hertzian radiations have been eliminated, he is referring to using ELF vibrations: "... the Hertzian effect has gradually been reduced through the lowering of frequency." (3)

2. "... the energy received does not diminish with the square of the distance, as it should, since the Hertzian radiation propagates in a hemisphere." (3)

3. He apparently detected resonator or standing wave modes: "... my discovery of the wonderful law governing the movement of electricity through the globe... the projection of the wavelengths (measured along the surface) on the earth's diameter or axis of symmetry... are all equal." (3)

4. "We are living on a conducting globe surrounded by a thin layer of insulating air, above which is a rarefied and conducting atmosphere... The Hertz waves represent energy which is radiated and unrecoverable. The current energy, on the other hand, is preserved and can be recovered, theoretically at least, in its entirety." (4)

As Dr. Corum points out, "The last sentence seems to indicate that Tesla's Colorado Springs experiments could be properly interpreted as characteristic of a wave-guide probe in a cavity resonator. (5) This was in fact what led Dr. Tesla to report a measurement which to this day is not understood and has led many to erroneously assume that he was dealing with faster than light velocities.

The controversial measurement: It does not indicate faster than light velocity

The mathematical models and experimental data used by Schumann and Waite to describe ELF transmission and propagation are complex beyond the scope of this paper. Dr. James F. Corum, Kenneth L. Corum and Dr. A-Hamid Aidinejad have, however, in a series of papers presented at the 1984 Tesla Centennial Symposium and the 1986 International Tesla Symposium, applied the experimental values obtained by Dr. Tesla during his Colorado Springs experiments to the models and equations used by Schumann and Waite. The results of this exercise have proved that the Earth and the surrounding atmosphere can be used as a cavity resonator for the wireless transmission of electrical power.

Dr. Tesla reported that .08484 seconds was the time that a pulse emitted from his laboratory took to propagate to the opposite side of the planet and to return. From this statement many have assumed that his transmissions exceeded the speed of light and many esoteric and fallacious theories and publications have been generated. As Corum and Aidinejad point out, in their 1986 paper, "The Transient Propagation of ELF Pulses in the Earth Ionosphere Cavity", this measurement represents the coherence time of the Earth cavity resonator system. This is also known to students of radar systems as a determination of the range dependent parameter. The accompanying diagrams from Corum's and Aidinejad's paper graphically illustrate the point.

We now turn to a description of the methods to be used to build, as Dr. Tesla did in 1899, a cavity resonator for the wireless transmission of electrical power.

PROJECT TESLA: The wireless transmission of electrical energy using Schumann resonance

It has been proven that electrical energy can be propagated around the world between the surface of the Earth and the ionosphere at extreme low frequencies in what is known as the Schumann Cavity. Experiments to date have shown that the electromagnetic waves of extreme low frequencies in the range of 8Hz, the fundamental Schumann resonance frequency, propagate with little attenuation around the planet within the Schumann resonance cavity. Knowing that a resonant cavity can be excited and that power can be delivered to that cavity similar to the methods used in microwave ovens for home use, it should be possible to resonate and deliver power via the Schumann cavity to any point on Earth. This will result in practical wireless transmission of electrical power.

Background

Although it was not until 1954-1959 when experimental measurements were made of the frequency that is propagated in the resonant cavity surrounding the Earth, recent analysis shows that it was Nikola Tesla who, in 1899, first noticed the existence of stationary waves in the Schumann cavity. Tesla's experimental measurements of the wavelength and frequency involved closely match Schumann's theoretical calculations. Some of these observations were made in 1899 while Tesla was monitoring the electromagnetic radiations due to lightning discharges in a thunderstorm which passed over his Colorado Springs laboratory and then moved more than 200 miles eastward across the plains. In his "Colorado Springs Notes", Tesla noted that these stationary waves "... can be produced with an oscillator," and added in parenthesis, "This is of immense importance." (6) The importance of his observations is due to the support they lend to the prime objective of the Colorado Springs laboratory. The intent of the experiments and the laboratory Tesla had constructed was to prove that wireless transmission of electrical power was possible.

Schumann resonance is analogous to pushing a pendulum. The intent of Project Tesla is to create pulses or electrical disturbances that would travel in all directions around the Earth in the thin membrane of non-conductive air between the ground and the ionosphere. The pulses of waves would follow the surface of the Earth in all directions expanding outward to the maximum circumference of the Earth and contracting inward until meeting at a point opposite to that of the transmitter. This point is called the antipode. The traveling waves would be reflected back from the anti-pode to the transmitter to be reinforced and sent out again.

At the time of his measurements Tesla was experimenting with and researching methods for "... power transmission and transmission of intelligible messages to any point on the globe." Although Tesla was not able to commercially market a system to transmit power around the globe, modern scientific theory and mathematical calculations support his contention that the wireless propagation of electrical power is possible and a feasible alternative to the extensive and costly grid of electrical transmission lines used today for electrical power distribution.

The Need for a Wireless System of Energy Transmission

A great concern has been voiced in recent years over the extensive use of energy, the limited supply of resources, and the pollution the environment from the use of present energy conversion

systems. Electrical power accounts for much of the energy consumed. Much of this power is wasted during transmission from power plant generators to the consumer. The resistance of the wire used in the electrical grid distribution system causes a loss of 26-30% of the energy generated. This loss implies that our present system of electrical distribution is only 70-74% efficient.

A system of power distribution with little or no loss would conserve energy. It would reduce pollution and expenses resulting from the need to generate power to overcome and compensate for losses in the present grid system. Based on the 1971 world-wide power generation of 908 million kilowatts, approximately 207 million kilowatts are being produced to make up losses. This results in a cost of 454 billion U.S. dollars at 5 cents a kilowatt. The power wasted in transmission now costs over 100 billion dollars a year. Wireless transmission of power, if fully utilized, could save over 90 billion dollars per year. Any technology that can reduce these losses and the corresponding costs is of extreme importance.

The proposed project would demonstrate a method of energy distribution calculated to be 90-94% efficient. An electrical distribution system, based on this method would eliminate the need for an inefficient, costly, and capital intensive grid of cables, towers, and substations. The system would reduce the cost of electrical energy used by the consumer and rid the landscape of wires, cables, and transmission towers.

There are areas of the world where the need for electrical power exists, yet there is no method for delivering power. Africa is in need of power to run pumps to tap into the vast resources of water under the Sahara Desert. Rural areas, such as those in China, require the electrical power necessary to bring them into the 20th century and to equal standing with western nations.

As first proposed by Buckminster Fuller, wireless transmission of power would enable world-wide distribution of off-peak demand capacity. This concept is based on the fact that some nations, especially the United States, have the capacity to generate much more power than is needed. This situation is accentuated at night. The greatest amount of power used, the peak demand, is during the day. The extra power available during the night could be sold to the side of the planet where it is day time. Considering the huge capacity of power plants in the U.S. this system would provide a saleable product which could much to aid our balance of payments.

In 1971, nine industrialized nations, (with 25% of the world's population), used 690 million kilowatts, 76% of all power generated. The rest of the world used only 218 million kilowatts. By comparison, China generated only 17 million kilowatts and India generated only 15 million kilowatts (less than two percent each). If a conservative assumption was made that the three-quarters of the world which is only using one-quarter of the current power production were to eventually consume as much as the first quarter, then an additional 908 million kilowatts will be needed. The demand for electrical power will continue to increase with the industrialization of the world.

A system of wireless transmission of power would make electrical energy available to people and nations which are not now privileged with the access to power developed nations take for granted.

Project Tesla: Objectives

The objectives of Project Tesla are divided into three areas of investigation:

1. Demonstration that the Schumann Cavity can be resonated with an open air, vertical dipole antenna;

2. Measurement of power insertion losses;

3. Measurement of power retrieval looses; locally and at a distance.

Methods

A full size, 51 foot diameter, air core, radio frequency resonating coil and a 120 foot tower have been constructed and are operational at an elevation of approximately 11,000 feet (3350 meters) for the experiment. This system is centered around a very powerful resonating Tesla coil. It was originally built in 1973-1974 and used until 1982 by the United States Air Force at Wendover AFB in Wendover, Utah. The USAF used the coil for simulating natural lightning for testing and hardening fighter aircraft. The system has a capacity of 150 kilowatts. The coil, which is the largest part of the system, has already been built, tested, and is operational.

A location at a high altitude is initially advantageous for reducing atmospheric losses which work against an efficient coupling to the Schumnann cavity. The high frequency, high voltage output of the coil will be half wave rectified using a uniquely designed single electrode X-ray tube. The X-ray tube will be used to electrostatically charge a 120 ft. (37 m) tall, vertical mast which will function to provide a vertical current moment. The mast is topped by a metal sphere 30 inches (75 cm) in diameter. A circulating current of 1,000 amperes in the system will create an ionization and corona causing a large virtual electrical capacitance in the medium surrounding the sphere. Discharging the antenna 7-8 times per second through a fixed or rotary spark gap will create electrical disturbances, which will resonantly excite the Schumann cavity, and propagate around the entire Earth.

The propagated wave front will be reflected from the antipode and reflected to the transmitter site. The reflected wave will be reinforced and again radiated when it returns to the transmitter. As a result, an oscillation will be established and maintained in the Schumann cavity. The loss of power in the cavity has been estimated to be about 6% per round trip. If the same amount of power is put into the cavity on each cycle of oscillation of the transmitter, there will be a net energy gain which will result in a net voltage, or amplitude increase. This will result in reactive energy storage in the cavity. As long as energy is delivered to the cavity, the process will continue until the energy is removed by heating, lightning discharges, or as is proposed by this project, loading by tuned circuits at distant locations for power distribution.

The resonating cavity field will be detected by stations both in the United States and overseas. These will be staffed by engineers and scientists who have agreed to participate in the experiment.

Measurement of power insertion and retrieval losses will be made at the transmitter site and at distant receiving locations. Equipment constructed especially for measurement of low frequency electromagnetic waves will be employed to measure the effectiveness of using the Schumann cavity as a means of electrical power distribution. The detection equipment used by project personnel will consist of a pick-up coil and industry standard low-noise, high gain operational amplifiers and active band pass filters.

In addition to project detection there will be a record of the experiment recorded by a network of monitoring stations that have been set up specifically to monitor electromagnetic activity in the Schumann cavity. This effort is headed by Dr. D.D. Sentman who is with the Institute of Geophysics and Planetary Physics at the University of California at Los Angeles. Dr. Sentman's project is funded by Los Alamos National Laboratory, the Lawrence Livermore Laboratory, and the National Aeronautics and Space Administration. Dr. Sentman has agreed to participate in verification of the goal of this proposal.

Evaluation Procedure

The project will be evaluated by an analysis of the data provided by local and distant measurement stations. The output of the transmitter will produce a 7-8 Hz sine wave as a result of the discharges from the antenna. The recordings made by distant stations will be time synchronized to ensure that the data received is a result of the operation of the transmitter.

Power insertion and retrieval losses will be analyzed after the measurements taken during the transmission are recorded. Attenuation, field strength, and cavity Q will be calculated using the equations presented in Dr. Corum's papers. If recorded results indicate power can be efficiently coupled into or transmitted in the Schumann cavity, a second phase of research involving power reception will be initiated.

Regulating Agencies

The Radio Regulations of the International Telecommunications Union (ITU), Article 2, Section 11, Geneva; 1959, list world-wide frequency allocations from 10 kilohertz to 275 gigahertz. Frequencies below 10 kilohertz and above 275 gigahertz are not allocated. In the United States the Federal Communications Commission has allocated frequencies in accordance with ITU regulations. In effect, there is no governmental agency in the world that has jurisdiction over the frequency of operation of Project Tesla.

Environmental Considerations

The extreme low frequencies (ELF), present in the environment have several origins. The time varying magnetic fields produced as a result of solar and lunar influences on ionospheric currents are on the order of 30 nanoteslas. The largest time varying fields are those generated by solar activity and thunderstorms. These magnetic fields reach a maximum of 0.5 microteslas (uT). The magnetic fields produced as a result of lightning discharges in the Schumann cavity peak at 7, 14, 20 and 26 Hz. The magnetic flux densities associated with these resonant frequencies vary from 0.25 to 3.6 picoteslas per root hertz.

Exposure to man-made sources of ELF can be up to 1 billion (1000 million) times stronger than that of naturally occurring fields. Household appliances operated at 60 Hz can produce fields as high as 2.5 mT. The field under a 765 kV, 60 Hz power line carrying I amp per phase is 15 uT. ELF antennae systems that are used for submarine communication produce fields of 20 uT. Video display terminals produce fields of 2 uT, 1,000,000 times the strength of the Schumann resonance frequencies. Project Tesla will use a 150 kw generator to excite the Schumann cavity. Dr. Corum's calculations predict that the field strength due to this excitation at 7.8 Hz will be on the order of 46 picoteslas.

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High altitude Project Tesla transmitter, Leadville, Colorado

A quarter-wave coaxial cavity as a power processing plant

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The coaxial conductor geometry has been a subject of interest in electrical engineering since the advent of radio and the foundations of the radio engineering discipline. The simplicity of this geometry and the resonant modes associated with it, have attracted scientists to return to the development of different technologies and analytic models utilizing the coaxial geometry time and again. Almost all of these have been developed in the areas of communication technologies and have utilized portions of classical transmission line theory for the basis of their respective analytic models.

The limited scope of communication technologies has focused attention to a limited level (small energies) of applications of the complex electromagnetic nature of resonant circuits and physical properties they possess which may be exploited. The analytical simplicity of the coaxial geometry provides for a distributed resonant structure which has modes that can be physically interpreted and visualized with qualitative links to the analysis through transmission line theory but, as is often the case, the complexity of model analysis of cavity resonators hinders the physical interpretation of their properties.

The coaxial resonator may be viewed as a transitional geometry falling between transmission line and cavity resonators. With a proper analytic synthesis of the field theory, transmission line models, the lumped equivalent model, and cavity and waveguide analytic considerations, a broader and more complete understanding of all distributed resonant structures may be gained.

It becomes apparent with a review of analytic models, that appreciation for the potential offered by resonant cavities as RF power processing elements has remained undeveloped. This essentially new area (RF Power Processing) of Radio Frequency Engineering has potential.

Lumped Circuits

The lumped equivalent transmission line model is presented in many undergraduate electromagnetics texts and is considered one of the classical analytic techniques of electrical engineering. The origins of this analysis can be traced to the works of Oliver Heaviside (1880's) and S. A. Schelkunoff (1) (1930's). It provides the means by which distributed circuits may be compared to, and analyzed as, lumped circuits and is a critical analytical link between lumped and distributed resonant systems. The usual presentation of the model is focused on the development of the impedance transforming properties of transmission line matching networks and does little to demonstrate or emphasize the resonant rise phenomenon. Figure 1 illustrates the it, $\lambda/4$ coaxial resonator as it would be represented in lumped equivalent circuit theory. As the analysis of distributed circuits represented in this form is extensive it will not be repeated here.

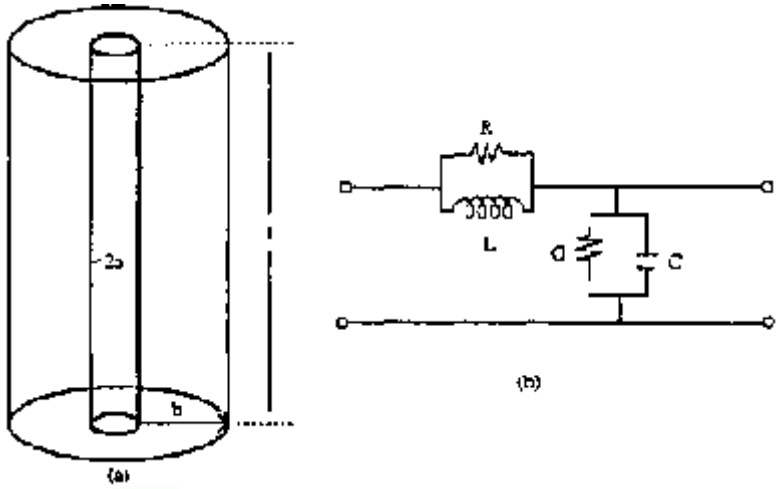

Figure 1(a): The $\lambda/4$ coaxial resonator - 1(b): The lumped equivalent circuit

The equations for the lumped equivalent parameters and the characteristic impedance are:

$$L = \frac{\mu}{2\pi}\ln(b/a) H/m \quad (1)$$

$$C = \frac{2\pi\varepsilon}{\ln(b/a)} F/m \quad (2)$$

$$R = \frac{R_S}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)\frac{\Omega}{\pi};\ R_S = \sqrt{\frac{\pi f \mu_{cond}}{\sigma_{cond}}} \quad (3)$$

$$G = \frac{2\pi\sigma}{\ln(b/a)} S/m \quad (4)$$

$$Z_0 = 60\ln(b/a)\Omega$$

Resonance

The phenomenon of the resonant rise on a transmission line, and in any cavity resonator, is physically due to coherent reflection of forward and backward traveling waves occurring at critically spaced terminating surfaces. The occurrence of standing waves, or stationary field distributions, is common to all resonators and is indeed the mechanism by which energy storage and voltage, current and impedance transformation are realized in distributed circuits.

The simple field distributions of most cavity resonators share great qualitative, and indeed some analytic similarities with the standing waves present on transmission line resonators. A thorough conceptual appreciation of the phenomenon of resonant rise may be obtained from consideration of a vector diagram representation of the incident (E1) and reflected (E2) waves on a resonant length of line. Figure 2 shows the familiar sinusoidal voltage distribution associated with the open circuited lossless resonant line and the resulting phases of the two waves at different points in the distribution (2). Under lossless conditions the load reflection coefficient is unity with zero phase

angle and the load impedance is infinite. As a result, the incident and reflected waves have equal magnitudes at the load, and the reflection occurs such that the resulting phases of the two waves are also the same. As the figure demonstrates, this phenomenon yields a terminal point voltage that is the arithmetic sum of the incident and reflected components.

EL = $2E_1 = 2E_2$ (6)

It should also be noted that in this ideal case the currents of the incident and reflected wave are equal in magnitude but opposite in phase. Thus, the vector sum is zero and the current into the load is zero.

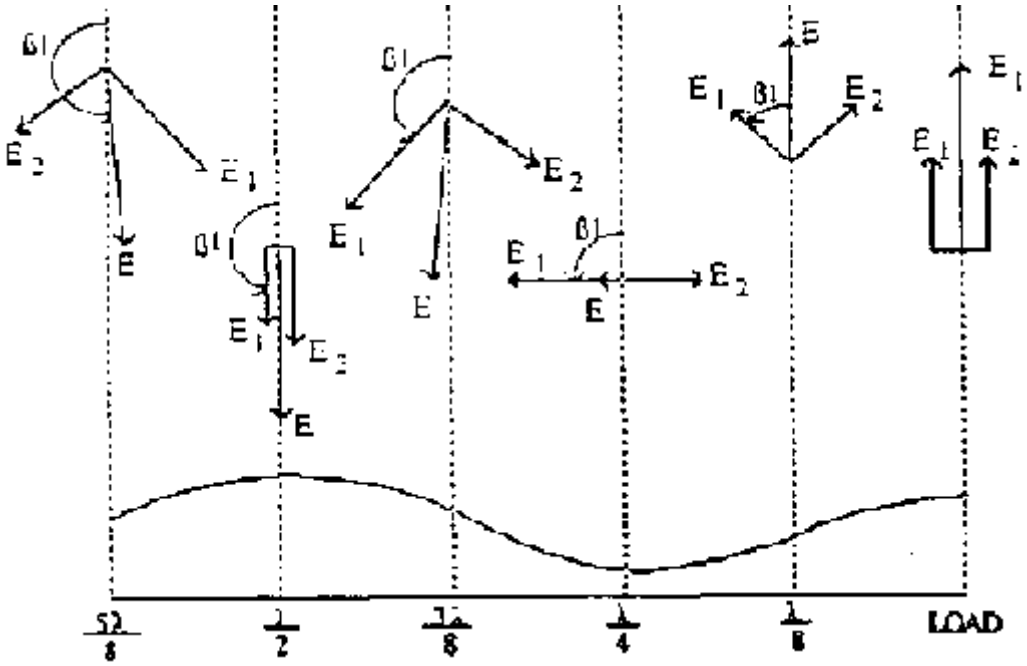

Figure 2. Vector Diagram representation of the incident and reflected voltage waveforms on resonant transmission lines (2)

The criteria for resonance is inherent in the spatial voltage distribution and requires the voltage maximum and minimum be separated by one quarter wavelength. This means that regardless of the loading, the system must be, electrically, ninety degrees long. This can be easily demonstrated with a Smith chart analysis of the capacitively loaded $\lambda/4$ resonator.

Foreshortened Coaxial Resonator

The example presented in this paper to illustrate the coaxial cavity resonator is a discharge device where the potential for discharge is built up in a spherical capacitor. It is appropriate to show how this capacitive load will change the operating parameters at the resonator. Numerical values presented are appropriate for the demonstration model. The material presented comes from published work (3) and is in part the result of mutual theoretical development conducted by the authors and Dr. F. Corum on this research project. (Some of this material will also be found in the monograph "Vacuum Tube Tesla Coils" by James F. Corum and Kenneth L. Corum).

For the capacitivly loaded transmission line, the length at resonance will be less than a quarter wavelength long due to the change in the angle of the reflection coefficient at the load end. The effect on the SWR is that the angle is reduced from 0 degrees, for a full $\lambda/4$ unloaded line, to a negative angle such that the reflection coefficient for the open-circuited end will be:

$\Gamma 2 - |\Gamma 2| / f$ where: f <0 (7)

The result of this change is that the line is not only physically shortened but that stationary >/4 sinusoidal field distribution is effectively shortened. Figure 3 shows the comparison between the unloaded and loaded distributions.

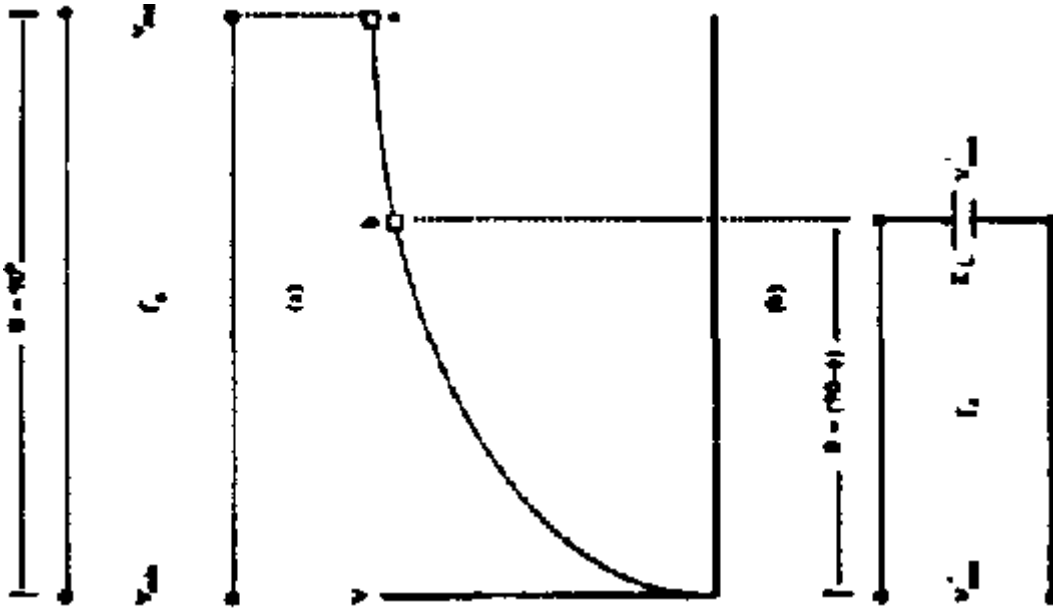

Figure 3. The capacitively foreshortened line: (a) unloaded line (b) voltage distribution (c) loaded line and resulting reduction in attained load voltage

Lumped Equivalent Example

Consider the resonator shown in Fig. 4 with its equivalent transmission line model. At the shorted input end (1) the impedance is (ZL = Rloss + j0) and the reflection coefficient ($\Gamma 1 = 0 < 180°$). At the load end (2) the capacitance of the sphere must be calculated and the load parameters evaluated.

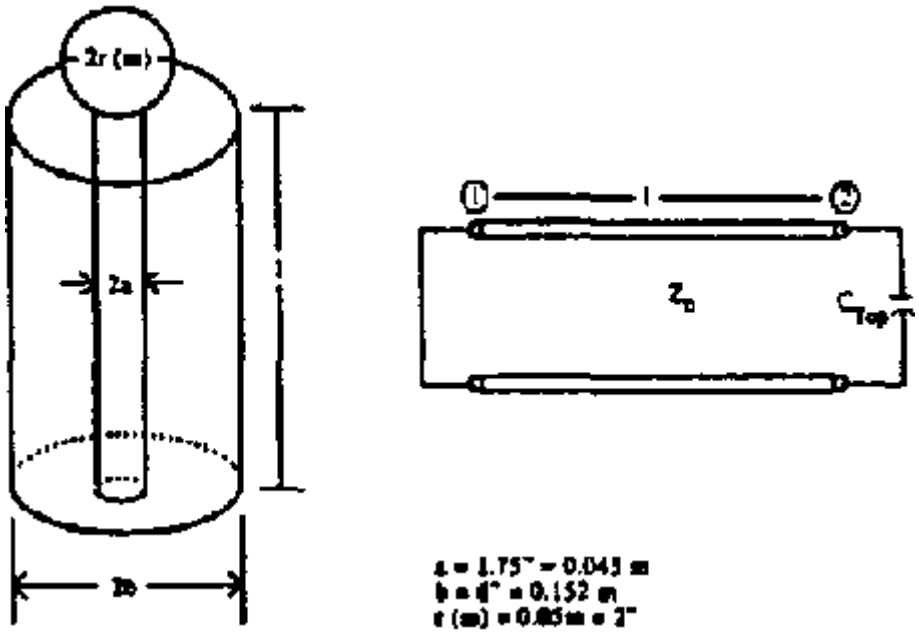

Figure 4. The capacitively top loaded coaxial cavity and its equivalent transmission line circuit for Smith chart analysis.

The capacitance to ground of an isolated sphere is given below and may be used as a reasonable approximation for the top loaded sphere.

C sphere = 4 pe o r (m) (8)

Where r(m) = radius in meters

Thus C top = 5.65 pF

The unloaded $\lambda/4$ resonant frequency of the line is calculated from:

$c = \lambda / 4 = 41$ (m)f, or f = c/ 41(m). (9)

This yields: f=100 Mhz, and $\omega = 2\pi f = 6.28 \times 10^8$ rad/sec.

Thus the proper load impedance is:

$$X_l = 1/j\omega C_{top} = 1/j\,2\pi f C_{top} = 281.7\Omega \quad (10)$$

The characteristic impedance of the resonator in an air dielectric is:

$$Z_0 = 60\ln(b/a) = 74.0\Omega \quad (11)$$

The normalized load reactance is:

$$X_l' = X_l / Z_0 = 3.81 \quad (12)$$

The effect of the loading capacitance is to require the line to be shortened to maintain the same resonant frequency or to lower the resonant frequency when added to a line of given length. The electrical line length with C top as a load will be:

I' (λ_0) = 0.25 λ_0 = 0.2875 λ_0 (13)

or

l'(m) = I' (λ_0) λ_0 (m) = 0.863 m

and the resulting resonant frequency is:

f' = C/4 I'(m) = 86.91 Mhz (14)

Coaxial Cavity Resonator

A transition from resonant transmission line to resonant cavity occurs for the coaxial line when the input is short circuited as shown in the Figure 5. Several things become apparent with this fundamental observation. The structure takes on the nature of a completely enclosed system, or hohlraum as they have been called (4), like that of a cavity is a traditional geometry exhibiting properties of both waveguides and cavities and is an important conceptual link for developing all classes of cavity resonators for application as RF power processing elements.

It may be shown that optimal dimensions of the coaxial cavities may be developed from criteria for maximizing the energy storage (Q) and step up (SWR) of the cavity. The criteria for development of maximum Q may be seen in the optimization of the Q from power considerations. The Q of a resonant cavity is defined as before:

$$Q = \frac{f_0}{2\Delta f} = \frac{(2\pi \text{ energy stored})}{(\text{energy dissipated per Cycle})} \quad (15)$$

The energy stored and dissipated is approximated as:

Energy stored = $\iiint \Phi^2 dv$ and Energy dissipated = $\iint \Phi ds$

Therefore:

$$Q \cong \frac{VOL}{A_s}$$

Thus, Q may be maximized for the geometry which yields the largest volume to surface area ratio. This occurs for the coaxial cavity when the ratio of (b/a) equals 3.6 and the resonator has a

characteristic impedance (Z_c) of 76.9 Ω (5). A comparison of obtainable unloaded Q's for different resonant systems is insightful. Table 1 shows the representative magnitudes of the various unloaded resonant circuits.

Table 1: Magnitudes of R sh for Resonant Structures

TYPE OF CIRCUIT	R_{SH} (MAGNITUDE) Ω
Lumped Tank	10,000
Tesla Coil	100,000
λ_4 Coaxial Resonators	100,000
Cavity Resonators,	1,000,000

.
The trend in increasing "Q" with increased volume to surface area may be seen progressing down the table. The coaxial cavity fares well comparatively with all structures and was chosen for the simplicity of construction and design as well as its representative nature. The Q's of cavity resonators exceed those of coaxial resonators by an order of magnitude and might be chosen as a superior system for certain applications of power processing.

The criteria for the development of maximum step-up (SWR) parallels the shunt resistance considerations since R sh - SWR.

$$R_{sh} = \frac{\left|\int V dl\right|^2}{P\,diss} \quad (17)$$

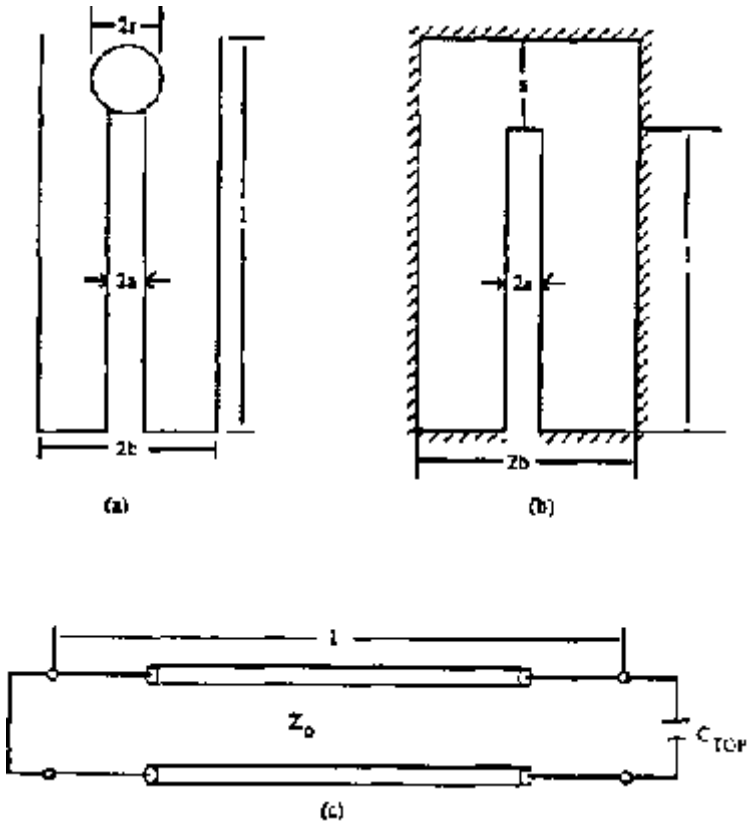

Figure 5. The quarter wavelength capacitively loaded cavity:

(a) spherical capacitively top-loaded cavity
(b) foreshortened capacitivly loaded cavity
(c) transmission line equivalent

It is obvious that the shunt resistance is a function of the conductor losses and loading. The maximum shunt resistance occurs for b/a = 9.2 which yields a characteristic impedance of 133.1 Ω (5).

Again, a comparison of obtainable shunt resistance (R sh) for different resonant systems is insightful. Table 2 shows the representative magnitudes of the various unloaded resonant circuits.

Table 2: Magnitudes of "Q_u" for Resonant Structures

TYPE OF CIRCUIT	Q_u (MAGNITUDE)
Lumped Tank	100
Tesla Coil	100
$\lambda/4$ Coaxial Resonators	1000
Cavity Resonators	100,000

RF Power Processing

The first individual in the literature to realize that the RF resonant systems might be used to advantage in the processing (or transformation) of large electrical energies for engineering applications was Nikola Tesla. He first developed the "distributed helical resonator" strictly as a means of generating high voltages and the resulting spectacular discharges for which he is famous. He completed extensive empirical testing and optimization of this structure during the late 1890's and proposed a variety of possible applications including wireless transmission of power and the concept of directed energy weapons.

When examining Tesla's Colorado Springs Device as a model for a power processing system four basic processes can be observed. The conversion of power from 60 Hz to RF; the transformation by pulse modulation to high peak power and variable duty factor; the input coupling system; and the output couple to the load, Figure 6. These block components may be implemented by standard RF techniques in a variety of ways depending on the magnitude of the powers to be processed and the desired efficiency. The blocks comprising the resonator have been developed in the preceding sections and only the source considerations remain to be considered. Tesla implemented pulse moderation via a special breakwheel. As the break occurs and the spark is quenched (Tesla used a magnetic field and forced-air to quench the spark quickly). The high voltage transformer reactance is reintroduced across the primary tank detuning it to lower the "Q pri" and reduce the impedance which is coupled into the secondary. The secondary, which is now free of the loading of the ringing primary, now rings at its self resonant frequency (f sec) which is identical to that of the extra coil where the voltage (V sec) is stepped by resonant rise (VSWR). The primary capacitance (C p) is recharged during the break interval.

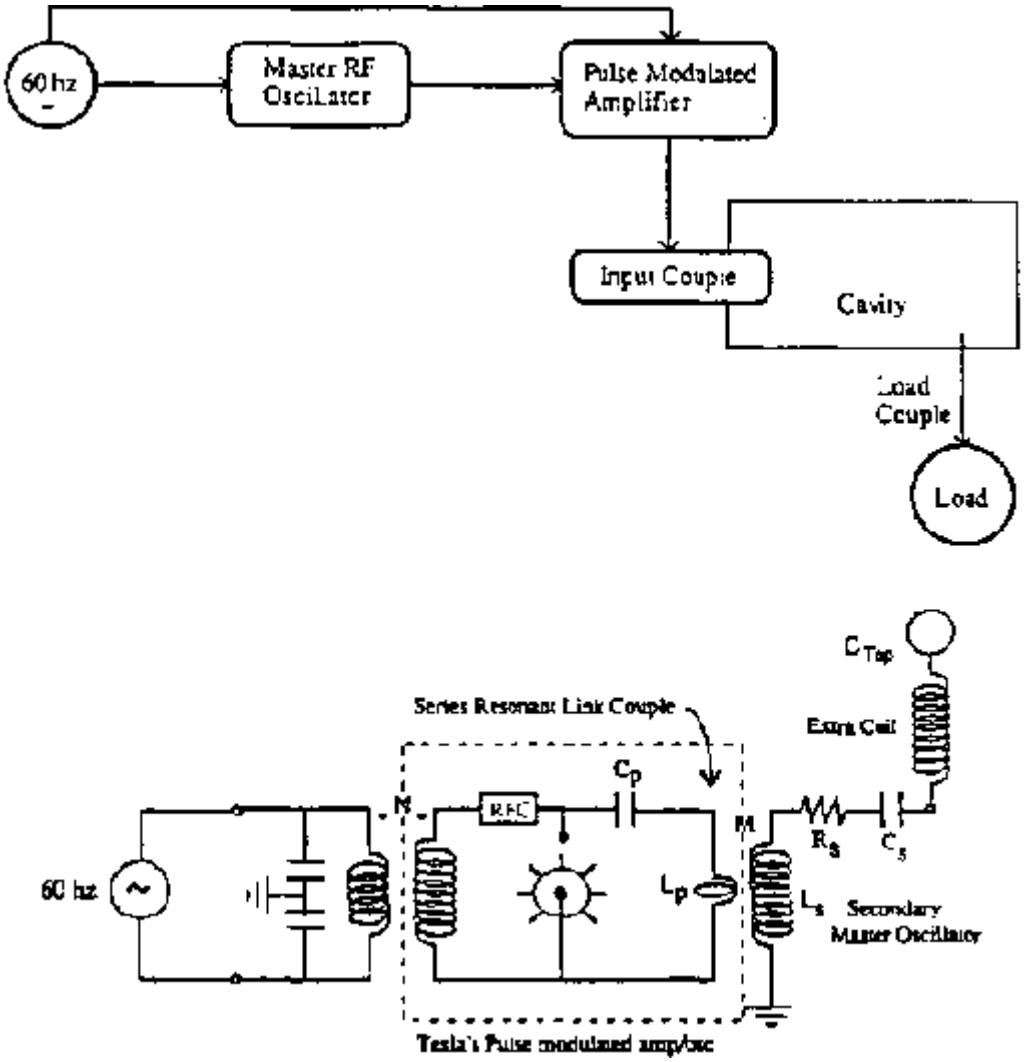

Figure 6: (a) Block diagram of typical RF power processing system (b) Tesla's 1899 Colorado Springs apparatus system equivalent. (3)

The spark interval during the exchange of energy between the primary and secondary must be carefully controlled to avoid reflection of energy back into the primary. For efficient operation, the optimal spark dwell must be used. This provides for trapping of the energy in the secondary/ extra

coil circuit which can be charged over many spark and break intervals to very large power levels. With repeated pulses of peak energy from the primary, the secondary master oscillator will charge the extra coil, and the system achieve base voltages which, when stepped by the extra coil, will exceed the breakdown potential of (C top). It should be noted that with the tight coupling used by Tesla in 1899 (k=0.6) practical for any of the resonator types, the breakwheel was required to switch with less than two cycles of oscillation i.e.:

$$\tau_{spark} = \frac{1}{100kHz} = 10\mu sec$$

This is a phenomenal achievement with a breakwheel switch or modulator. This became the fundamental limitation preventing Tesla from exploring higher frequencies and smaller resonator geometries. The advent of the vacuum tube switch (not the oscillator) would remove some of these limitations.

State-of-the-Art Switching

The appropriate engineering choice of a vacuum tube replacement for the breakwheel is the hydrogen thyatron switch. State-of-the-art tubes achieve rise times on the order of a few nanoseconds and fall times (deionization times) on the order of ten nanoseconds. If it is assumed that the pulse duration must be on the order of twice the fall time to provide an efficient waveform, it is obvious that attainable frequencies are no greater than 100 MHz. This may seem surprising considering the frequencies attainable by "Class C" oscillators (GHz). However, with the currently available dielectric insulators this is as high a frequency (due to the resulting physical sizes) at which the physical dimensions of any of the open or cavity resonators can hope to be effectively insulated for high power applications (hundreds of kilowatts).

A variety of power oscillators designs have been developed for different applications in industry and have become part of many standard texts on vacuum tube electronics. One in particular suggests the basis for the development of another alternative. In the tuned grid-tuned plate oscillator the grid circuit acts as a master oscillator to drive the parallel tank in the plate circuit. The plate tank is tuned to a slightly different frequency from the grid circuit to provide a capacitive impedance large enough such that the capacitance in combination with that from the grid to plate of the tube meets the Barkhausen criterion. The use of a master oscillator is one critical element advantageous for driving a resonator, the removal of the double tuned circuit from the plate is another. Both of these may be achieved with a modified form of the tuned grid-tuned plate oscillator.

The general arrangement of this power oscillator is shown in Figure 7. It is to be noted that the link is untuned and must be constructed such that the grid to plate capacitance does not bring it to resonance and develop parasitic oscillations. This configuration avoids the spectral line splitting and efficiency limitations of the double tuned plate circuit and allows tight coupling to be utilized for efficient energy transfer to the resonator.

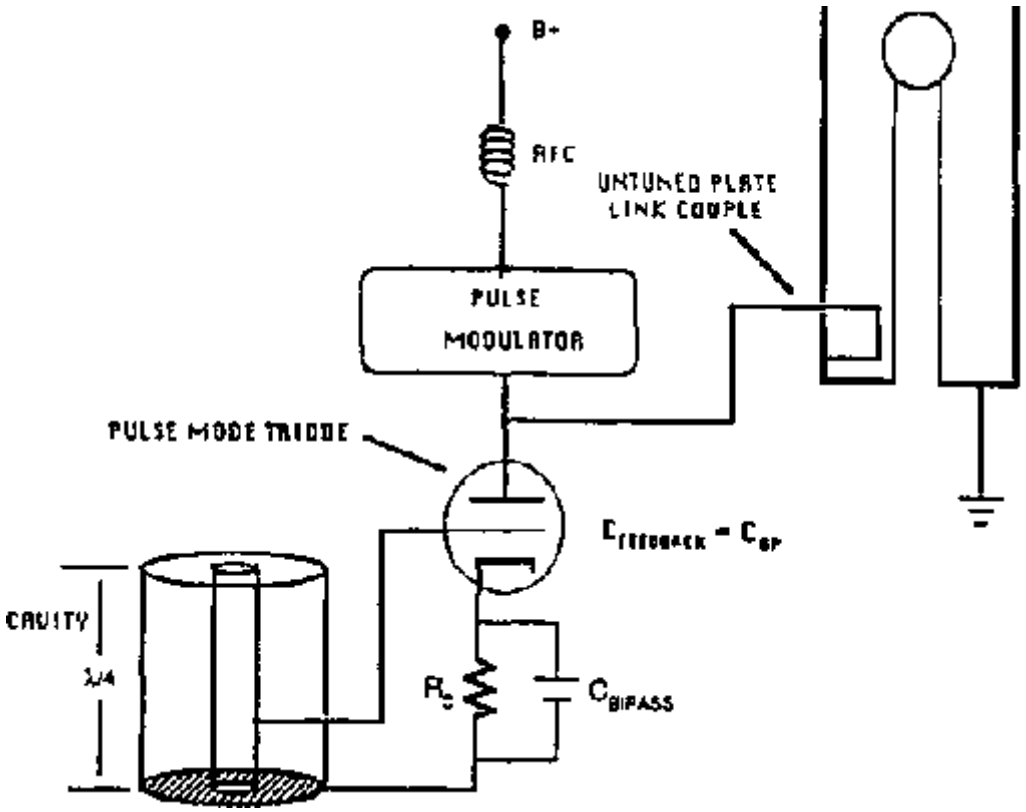

Figure 7: The optimal vacuum tube source configuration utilizing a tuned grid plate pulse modulated amplifier/oscillator with feedback via the grid to plate capacitance.

This is essentially a means of implementing an untuned plate circuit link coupled to the cavity resonator. The configuration places a master oscillator tank in the grid circuit so that the inefficiency of double tuned, coupled circuits is not present during the transfer of energy from the resonator to the high voltage discharge of the load. This is essentially a system paralleling the Colorado Springs Device and utilizing the insight provided by Sloan (6) in his work with early vacuum tube oscillators. The use of a distributed circuit (cavity) oscillator tank is advantageous in minimizing the tank circuit losses (principally the dielectric losses associated with gaseous dielectrics under pressure and the low losses characteristics of them. This characteristic bodes extremely well for the future application of resonant cavities to current high energy physics technologies.

Empirical Verification

Unfortunately the tubes needed to construct the device in Figure 7 do not exist or were not available. The capacitor discharge electrodes that were constructed were moderate in size and function well enough to give strong evidence of the potential for ~ /4 coaxial cavity resonators.

Two cavities were constructed and capacitively top loaded with small egg shaped (prolate spheroids) discharge electrodes as shown in Figure 8. The inner conductor length was chosen such that the electrodes partially protruded from the end of the outer conductor to provide for a compromise between minimization of the radiation resistance (cavity loading), the advantages of increased distance to the outer conductor (arc-over considerations), and the resulting visual display. Each of the geometries were empirically examined for agreement with the performance predicted by the analysis. And as the following analysis and results comparison shows, the empirical results of both were reasonable and fell within the expected magnitudes of performance.

As a result of a limited source power (= 200 watts C.W.) the magnitude of attainable voltage (= 20 KV) required the selection of very small spheroidal capacitor discharge electrodes. In fact any spherical capacitor designed to break down at approximately 20 kV has too low a capacitance to deliver any sizable charge to the spark discharge and to appreciably demonstrate lumped capacitive loading and foreshortening effects. The egg-shaped spheroid electrodes provide larger capacitance at a lower breakdown potential (though it is not accurately predictable). The concentration of

charge at the egg tip combined with the high E-field emission of charge for a small but impressively stable plasma discharge of two to four inches (5 to 10 cm) in length.

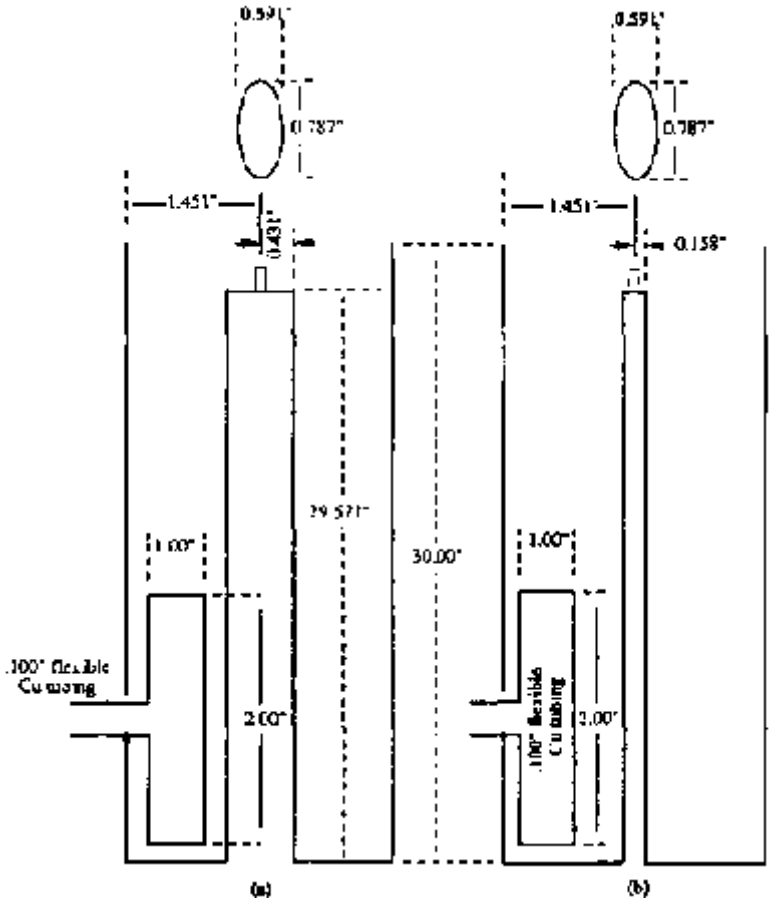

Figure 8: Experimental cavity dimensions (a) Cavity 1 b/a = 3.4; (b) Cavity 2 b/a = 9.2

The resonators were initially driven with a C.W. source (approximately 200 W) which yielded a vertical plasma (flame) two to three inches (5 to 7.5 cm) long which was fed or pumped by a bush type discharge approximately 1.0 to 1.5 inches (2.5 to 3.8 cm) in length. The source was then pulse modulated over a range of duty factors to allow the class A amplifier used to be driven at larger peak pulse powers while maintaining between 150 and 200 watts average power input.

This provided larger base voltages over pulse lengths sufficient to charge resonator to the breakdown potential of the discharge electrode. As a result of the larger base voltages obtained, the plasma length increased to between three and four inches (7.5 to 10 cm) fed by a brush type discharge 1.5 to 2.5 inches (3.8 - 6.3 cm) in length.

The brush type discharge is one of five types seen and characterized by Tesla in various experiments he conducted. As stated above, what was observed in this experiment was actually a I to 2.5 inch (2.5 - 6.3 cm) (this range in lengths covers the results obtained for both CW and pulse modulated sources) blue-white brush discharge occurring at rates sufficient to couple energy into and sustain a white RF plasma (two to four inches/five to ten cm long) producing temperatures at the base of the flame (not the hot centre) sufficient to melt the tip of an aluminum electrode (> 600 C). (Stainless steel was later introduced.) The larger discharges were achieved by pulse modulating the generator allowing the amplifier to be driven at higher powers for short pulse-periods (these being on the order of the fill time of the cavity). This produced higher peak voltages and hence the longer, hotter, and more stable discharges.

The discharges in the pulsed mode were driven with pulse repetition rates in the frequency range (100-10,000 pps). The modulation of the discharges at these frequencies produced an almost painfully loud audible frequency pitch. The frequency of the pitch was readily adjusted across the audio spectrum by varying the pulse repetition rate and the pitch was intensity was also seen to vary with changes in the pulse duration. This modulation, as well as the unmodulated excitation, was easily detected on FM radio receivers within a few hundred feet (approximately 100 m) due to

the intensity of the stray reactive fields off the end of the resonator. The radiated field components were measured at less than a milliwatt and are entirely negligible.

Coaxial Cavity Design Examples

The design of the coaxial cavity and the calculation of the parameters of interest for evaluating its performance, is directly obtained from analysis. The case of interest for evaluating the potential resonator performance and comparison to the empirical results is for the capacitively top loaded resonator with minimum loading presented by the input. coupling since this load can be effectively removed from the system by utilizing synchronous switching of the energy input.

The design parameters needed are:

a	=inner conductor radius (O.D)
b	= outer conductor radius (I.D)
la	= inner conductor length
or	(specify one or the other)
f	= desired frequency (MHz)
lb	= outer conductor length (if lb $\neq$ la)
Ctop	= top loading capacitance
ε_r	= relative dielectric permitivity

All dimensions will be worked in inches and frequencies in MHz unless otherwise specified. A reasonable estimate of Ctop is the first requirement. The top loading capacitance may be a spheroid or the foreshortening capacitance from the end of the inner conductor (terminated in a circular plate) to the outer conductor walls. Measurement of the cavity frequency responses were done with the spheroid discharge electrode removed and therefore with Ctop equal to the foreshortening capacitance. The recorded discharge parameters were obviously obtained with the spheroidal electrodes as the top loading capacitance.

The foreshortening capacitance may be roughly estimated from the area of the outer cylinder which extends beyond the inner conductor.

$$C_{top}^{fs.} = \frac{\varepsilon_0 A}{d} \quad (18)$$

Where:

A = π 2b(lb - la) = (area of the end of outer conductor)

d = b - a/2 = (mean distance to outer conductor)

The capacitance of the spheroid electrode used may be evaluated from an estimate of the mean diameter approximated by a cylinder of the same surface area.

$$C_{top}^{s.c.} = 4\pi\varepsilon_{r\,mean}(m) \quad (19)$$

This equation is for an isolated elevated sphere above a ground plane and does not account for the increased capacitance due to the vicinity of the surrounding outer conductor. For a rough approximation the value for the elevated body above a ground plane can be increased such that:

$$C_{top}^{i.e} = 1.5(C_{top}^{s.c.} \text{ over ground plane} \quad (20)$$

For small capacitance loads (Ctop << C) (i.e. when the top loading capacitance is less than ten percent of the resonator capacitance) a reasonable estimate of the foreshortened resonant frequency (fd) may be obtained as follows.

Determine the approximate frequency of operation (f_0) from the inner conductor strength.

$$f_a(Hz) = \frac{V_f c}{4l} \quad (21)$$

For linear conductors (fast wave structures) the velocity factor is assumed to be: Vf = 0. 999.

The load impedance is then calculated from the appropriate top loading capacitance.

$$Z_L = \frac{1}{j_\omega Ctop} \quad (22)$$

The characteristic impedance is:

$Z_0 = 60\ \mathrm{In}(b/a)$ (23)

The load reflection coefficient is then calculated from these values.

$$|\Gamma_2| \angle \phi = \frac{Z_L - Z_0}{Z_0 - Z_L} \quad (24)$$

The calculation of Γ_2 is unnecessary if there is no radiation resistance component included (i.e. Γ_2 = 1.0$<\phi^3$ for pure reactive loads) but is included here to demonstrate the effects of the loading resistance if it is not negligible (i.e. if large protruding discharge electrodes are used). At resonance:

$$\left[\phi - 2\beta\, la = -\pi\right] \text{ where: } \beta = 2\pi / \lambda_0 \quad (25)$$

Therefore, the approximate resonant wavelength is:

$$\lambda_0 - \frac{4\pi la}{\pi + \phi} \text{rad. or } -\frac{720^c la}{180^0 + \phi} \text{deg.} \quad (26)$$

The estimated resonant frequency (to within 2%) is then:

$$f_0 = \frac{V_f c}{V_f \lambda_0} \text{ or } f_0(Mhz) = \frac{11808.00(0.999)}{V_f \lambda_0 (in.)} \quad (27)$$

The electrical length of the resonator may be calculated from equation 28:

$$\theta = \beta_l = \frac{2\pi l}{V_t \lambda_0} \text{rad.} \quad (28)$$

The attenuation factor (α) is calculated from equation 29:

$$\alpha = 6.9462 \times 10^{-7} \frac{\sqrt{f(MHz)}\left[1 - \frac{b}{a}\right]}{2b \ln\left(\frac{b}{a}\right)} \text{Np / in.} \quad (29)$$

The propagation loss is (αl) and the Qu of the resonator can be calculated from equation 30.

$$Q = \frac{\pi}{4\alpha l}$$

The final parameter of interest before calculating the step-up is the base impedance (Rbase) calculated from equation 31.

$$Rbase = Z_0\left[\frac{1 - e^{2\alpha l}}{1 + e^{-2\alpha l}}\right] \quad (31)$$

Rbase is the input impedance of the cavity that the source (generator) would have to drive (or be matched to) if the resonator were to be driven by direct connection at the base.

The step-up is then calculated from equation 32.

$$\frac{Vtop}{Vbase} = \text{step up} = \frac{\left(\left[1 + |\Gamma_2|\cos\Phi\right]^2 + \left[|\Gamma_2 \sin\Phi\right]^2\right)^{\frac{1}{2}}}{\left(\left[e^{\alpha_1}\cos\theta + |\Gamma_2|e^{-\alpha_1}\cos(\phi - \theta)\right]^2 + \left[e^{\alpha_1}\sin\theta + |\Gamma_2 e^{-\alpha_1}\sin(\phi - \theta)\right]^2\right)^{\frac{1}{2}}} \quad (32)$$

Consider the following examples:

Example 1: Maximum "Q" Design b/a = 3.4:

Let:

a =	0.431 in. (1.095 cm)
b =	1.451 in. (3.686 cm)
la =	29.577 in. (75.126 cm)
lb =	30.000 in. (76.200 cm)
ε_r =	1.0

Example 2: Maximum (Rsh) Design b/a = 9.2:

Let:

a =	0.158 in. (0.401 cm)
b =	1.451 in. (3.686 cm)
la =	29.577 in. (75.126 cm)
lb =	30.000 in. (76.200 cm)
ε_r =	1.0

The results of these theoretical calculations are given in Table 3. It is to be noted that the results are from the estimated top loading capacitance and therefore are not strictly accurate. However, the estimates do agree well (within 1%) with operating frequencies measured in the lab and hence may be used with reasonable confidence.

Estimated Load C_{Top}	Z_o (Ohms)	Z_L (Ohms)	ϕ (Deg.)	Γ_o (Mhz)	θ (Deg.)	αl (Np)	Q_U	V_{Top}/V_{base}
Example 1 b/a = 3.8								
$C_{Top} = C_{DE}$ C_{Top} = 1.25pF	72.8	- j1273	- 6.55	96.08	86.81	2.47×10^{-4}	3180	664
$C_{Top} = C_{FS}$ C_{Top} = 0.7 pF		- j2274	- 3.67	97.68	88.26	2.52×10^{-4}	3120	596
Example 2 b/a = 9.2								
$C_{Top} = C_{DE}$ C_{Top} = 1.25pF	133.0	- j1273	- 11.93	93.10	84.12	3.14×10^{-4}	2500	656
$C_{Top} = C_{FS}$ C_{Top} = 0.7 pF		- j2274	- 6.69	96.01	86.75	3.19×10^{-4}	2460	591

Table 3. Tabulated theoretical results for critical parameters

The theoretical results are also obtainable, for the line without capacitive top loading, by calculating the lumped equivalent parameters and the equivalent equations to those above. This proves to be an appropriate method of calculation when coupling considerations and design are to be developed. The material constants of the cavity may also be changed from an air dielectric and copper conductor to any alternatives more easily than with the above method (the constants of the above equations include the material constants). A list of the material constants used is given below. The following calculations are done in meters to allow use of the more familiar constant values.

List of Material Constants

σ_{cu} =	5.65 x 10 mhos/m

μ_{cu} =	o = 1.257 x 10-6H/m
ε_r =	1.0
σ_{air} =	2.5 x 10- i 4 mhos/m

The propagation losses (αl) can now be calculated and the resulting Qu and the SWR determined from equations 33, 34.

$$SWR = \frac{1}{\alpha l} = \frac{8Z_0 f(Hz)}{RNc(m/s)} \quad (33)$$

The foreshortened SWR is then:

SWR' = SWR sin(90 - ϕ °) and

$$Qu = \frac{\pi f}{\alpha C} = \frac{2\pi f Z_0}{RC} \quad (34)$$

The results of the two examples are tabulated below for comparison.

Example 1: Maximum "Q" b/a = 3.6:

αl = 2.58 x 10^4 Nepers
Qu = 3,040
SWR = 3,880

Example 2: Maximum Rsh b/a = 9.7:

αl = 3.37 x 10^{-4} Nepers
Qu = 2,330
SWR = 2,970

Empirical Results:

The response curves of the two example cavities without capacitive top loading were measured in the lab with a link coupled input load on the cavity. The singly loaded "Q" of each was then calculated from plots of these curves shown in Figures 9 and 10. Though this is not directly comparable with the calculations of the unloaded "Q" above, it does place the magnitudes of the obtained results approaching the expected values.

f(MHz)	f_0(0dB)	f_L(-3dB)	$f_{u(}$-3dB)Q_L	
cavity 1	96.877	96.852	96.917	1938
cavity 2	95.640	95.611	95.690	1648

Table 4: Experimental Data for Determination of QL'

The loaded Q, (QL') was then calculated from equation 35:

$$Q = \frac{f_0}{2\Delta f_{L,U}} \quad (35)$$

The usual form of equation 35 in texts is:

$$Q = \frac{f_0}{\Delta f} \quad (36)$$

where; Δf is the difference in frequency found between the 3dB down points (Δf = fu - fL) of the response curve. The equation has been modified such that Δf is a measure of the difference in frequency between f_0 and the 3dB down points of the response curve (Δf = f_0 - fL) in this case.

This change was made to allow for the computation of the QL' such that the capacitive loading effects of the link couple, observable in the non-symmetric nature of the right half of the response curves (fo › › fu), did not effect the calculation and a closer approximation of the unloaded "Q" could be obtained (i.e. as close an approximation to the unloaded "Q" is desired). This loading is not a critical concern since it may be effectively removed by synchronous switching of the source energy. Thus, a reasonable approximation of the singly loaded Q (this is the "Q" with input coupling reduced to a minimum), QL', may be obtained from the equation:

$$Q_L' = \frac{f_0}{2\Delta f_L} \quad (37)$$

This is accomplished by minimizing the coupling (rotating the link such that it is parallel rather than perpendicular to the lines of magnetic flux) and measuring the response with a probe, achieving slight coupling to the reactive fields at the open end of the cavity as described above. The results obtained for QL' of each of the cavities are in Table 4 (and Figures 9,10) with the data needed to calculate them.

Empirical measurement of the step-up is prohibitive since any attempt to measure Vtop results in an additional capacitive load on the resonator and detunes it from resonance. A rough approximation of the potential can be made from the length of the brush discharge which is approximately:

$V_{\text{break down}}$ = 10 kv/in, = 10% (38)

The brush discharge was observable as a blue-white discharge beginning at the tip of the egg shaped discharge electrode as a typical arc, then forking or branching out at its end (over the final 30% of its length). It was most easily observed with a pair of welders goggles due to the surrounding white plasma (flame) which tended to wash out and mask the discharge outline. It is to be noted that all of the discharges occurred directly off the tip of discharge electrodes with vertical orientation, regardless of the orientation of the resonator (i.e. if the resonator was titled the discharge was maintained vertically).

The discharges were self initiating if the average power was of the magnitude of two hundred and fifty watts and the discharge electrode was clean. However, it could be started by placing a metal object such as a screwdriver tip near the tip of the electrode or passing a lit match across the tip with average powers on the order of 100 watts.

The brush discharges (not the plasma flames) of the respective cavities for the pulse modulated source were of the following dimensions, Table 5:

Table 5: Experimental values for determination of SWR'

Excitation	Device#	L_{dis}(in.)	L_{flame}(in.)	P_{avg}(Watts)

CW	cavity 1	1.0	2.0	200
CW	cavity 2	1.5	3.0	150
modulated	cavity 1	1.5	3.0	250
modulated	cavity 2	2.5	4.0	150

Example 1.

Ldis1 = 1.5 in. (3.8 cm)
Pavg = 250 W

Therefore; Vtop1 = 15.0 kv

Example 2:

Ldis2 = 2.5 in. (6.3 cm)
Vtop2 = 25.0 kv
Pavg = 150 W

The input voltage at the base of the resonator impressed by the generator may be estimated by:

$$Rbg = \frac{Z^2_0 \sin^2 \theta_1}{R} \quad (39)$$

From Figure 8, θ_1 (experimental) = 10°. So for cavity 1 with Z_0 = 72.8 Ω:

$$Rbg = \frac{(72.8)^2 \sin^2 10^0}{(50\Omega)} = 3.2\Omega \quad (40)$$

From Table 4:

$Vin_1 = | Rbg\ Pavg |^{1/2} = | (3.2)\ (250) |^{1/2} = 28.3$ Volts (41)

For cavity 2 with $Z_0 = 136.2\,\Omega$:

$$Rbg = \frac{(136.2)^2 \sin^2 10^0}{(50\Omega)} = 11.2\Omega \quad (42)$$

and:

$Vin_2 = |(11.2)(150)|^{1/2} = 40.9$ Volts (43)

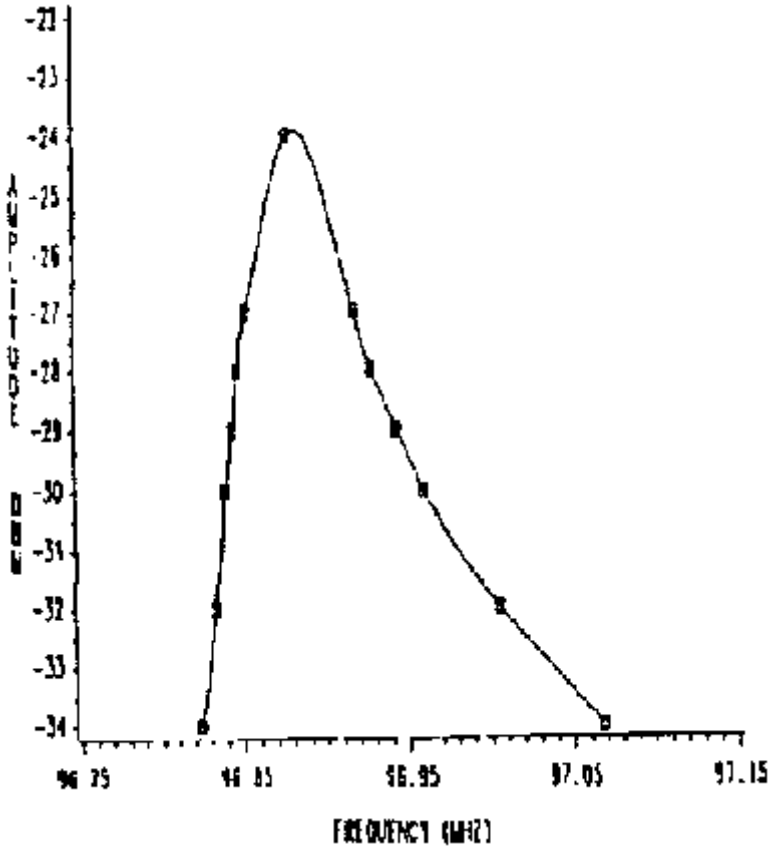

Figure 9. Response of cavity 1 (b/a = 3.4)

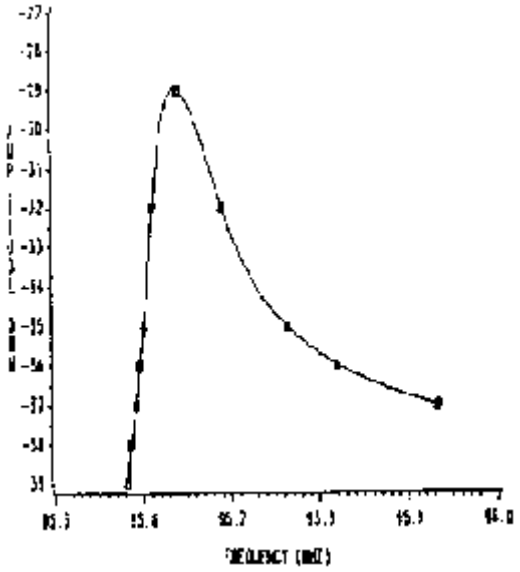

Figure 10. Response of cavity 2 (b/a = 9.2)

This yields the loaded step-up.

Example Cavity 1:

$$\text{step-up}_1 = \frac{15\text{kv}}{28.3\text{v}} = 530$$

Example Cavity 2:

$$\text{step-up}_2 = \frac{25\text{kv}}{40.9\text{v}} = 611$$

The step-up of cavity 2 should be approximately 25% higher than cavity 1 according to the analysis and as shown above, the experimental results fall within 10% of this predicted difference in the step-up.

Conclusions

The data did verify the ability to produce a discharge from the end of the inner conductor with relatively heavy loading on the cavity and unprecedented minimum power requirements with respect to the minimum power required to drive a Tesla coil to Ebreakdown with similar loading. Once started, either of the resonators were able to maintain the plasma of at least an inch with only fifty to sixty watts of input. Reduction in power input could be adjusted by reducing coupling or amplifier gain.

Recommendations have been made and commented on throughout the text to allow consideration of the topics as they are presented. The development of a full scale prototype RF power processing system is most definitely indicated to attain more accurate data as to the achievable efficiencies with state-of-the-art technologies. Additionally, a complete experimental determination of the loaded response of the cavity using pulsed excitation is necessary to evaluate the degree of efficiency obtainable with current technologies when using the phenomenon of switched resonant trapping. Such evaluation will allow targeting of new high power synchronous switch vacuum tube technologies for development.

Development of improved capacitive loads storing larger charge densities than uninsulated spherical discharge electrodes should be developed. The development of switches (controls) of high voltage discharges from such charge reservoir is feasible and should be investigated as a new high energy technology. This new application would provide means to accommodate the current directed energy technologies which might provide the needed impetus for further development of RF power processing technologies.

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LIST OF SYMBOLS

A =	magnetic vector potential
a =	(in.) inner conductors outer radius
b =	(in.) outer conductors inner radius
C =	(F/m) distributed equivalent capacitance

C_{Top} =	top (end) loading capacitance of resonator
C_{sphere} =	capacitance of an elevated metal sphere
c =	speed of light
d =	tap distance from shorted end of line
E =	electric field
f =	(Hz, MHz) frequency
f_0 =	circuit self resonant frequency
$f_{L,U}$ =	(Hz) lower and upper 3dB comer frequencies
G =	(Siemens/m) distributed equivalent shunt conductance
H =	magnetic field
i =	current
I =	current
K =	tapped x-mission line coupling constant
k =	coefficient of coupling
k_c =	critical coupling coefficient
L =	(H/m) distributed equivalent inductance
l =	l_a (in.) length of inner coax conductor
lb =	(in.) length of outer conductor if ($l_b \neq l_a$)

M =	mutual inductance coupling constant
N =	number of 114 wavelengths
Q =	resonant circuit quality factor
Q_{ul} =	unloaded Q
$Q_{l'}$ =	semi loaded Q (includes output end loading)
$Q_{l''}$ =	fully loaded Q (includes output end loading)
Q_{load} =	Q of the output (open end) load alone
r =	(m) radius of top loading spheroidal capacitance
R =	(Ω/m) distributed equivalent resistance
R_s =	skin effect resistance
R_o =	real portion of characteristic impedance
R_b =	resistance referred to the base of x-mission line
R_{bul} =	unloaded base equivalent transmission line resistance
S =	VSWR
T =	(sec.) phase period
T_{beat} =	(sec.) beat period of exchange of energy
t_{fill} =	(sec.) cavity resonator fill time
V_f =	velocity factor of a distributed circuit

v =	longitudinal phase velocity
X_L =	(Ω) load reactance of resonator (x-mission line)
Y =	(mhos)admittance
Z =	(Ω) impedance
Z_0 =	characteristic impedance of distributed circuit
Z_{in} =	impedance referred to the base of the line
$Z_{o.c.}$ =	impedance referred to open circuited end of line
$Z_{s.c.}$ =	impedance referred to shorted end of line
GREEK SYMBOLS	
α =	propagation attenuation constant
β =	propagation phase constant
Γ =	transmission line reflection coefficient
$\Gamma\|$ =	magnitude of reflection coefficient
γ =	($\alpha + j\beta$) longitudinal propagation constant
ε =	dielectric permitivity
ε_0 =	free space dielectric permitivity
η =	vacuum tube plate circuit efficiency
θ =	transmission line electrical length

λ =	wavelength
λ_0 =	free space wavelength
λ_g =	wavelength in propagating media and conductor
μ =	conductivity
ρ =	current density
σ =	conductance
τ =	pulse duration
τ_w =	cavity fill time rate constant
Φ =	magnetic flux
ϕ =	transmission line reflection coefficient phase
ω =	radian rotational frequency