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RAPID COMMUNICATION

A new mode of radio communication

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Abstract. Aspects of electromagnetic theory proposed recently point to a possible new mode of radio communication. Such communication would occur via a 'companion wave', a heretofore unknown wave behaviour associated with a radio wave propagating in a superimposed magnetic field. A method of realizing this mode of communication within conventional radio science is outlined.

It has been proposed recently that pulsed magnetic energy may spread limitlessly in free space through the agency of a conventional electromagnetic (EM) wave and a newly derived companion wave [1]. The latter is a real and observable energy density wave generated when an EM wave propagates with its magnetic field parallel to an external magnetic field. This companion wave can carry radio signals in addition to and distinct from those carried by the EM wave, even after the EM wave signal-carrying capacity has been fully utilized. Conceivable realms of applicability of this idea include wireless communication of all types.

The present communication reports two further results, both of which have the effect of bringing the original idea closer to the realm of applicability. The first concerns the original assumption of the presence of a pervasive static magnetic field (such as the Earth's magnetic field) between the points of transmission and reception. This assumption was made for the purpose of intuitive development of the idea. That restrictive requirement is now removed. Second, the concept of a new device called the *force-measuring* antenna was introduced to demonstrate the observability of the companion wave. The companion wave signal is now shown to be observable within conventional radio science using conventional antennae, without necessitating the new device.

To give the discussion specificity, figure 1 shows a transmitting electric dipole antenna T and a similar receiving antenna R separated by a distance D in a rectangular coordinate system. The transmitted electric and magnetic fields at any location $\boldsymbol{r}$ are

$$\boldsymbol{e} = \boldsymbol{e}_0(\boldsymbol{r})\sin(\omega t - kr) \qquad (1)$$

$$\boldsymbol{b} = \boldsymbol{b}_0(\boldsymbol{r})\sin(\omega t - kr) \qquad (2)$$

where $\omega = 2\pi f$ (f is the frequency of the wave), $k = 2\pi/\lambda$ (λ is the wavelength), and e_0 and b_0 are the field amplitudes. In the presence of an external magnetic field $\boldsymbol{B}(\boldsymbol{r})$, there arises a theoretical interaction energy density term (considered so far to be an unobservable mathematical subtlety of the EM theory):

$$u(\boldsymbol{r}) = \boldsymbol{B}(\boldsymbol{r})\cdot\boldsymbol{b}(\boldsymbol{r})/\mu_0 \qquad (3)$$

μ_0 being the magnetic permeability of free space. The flux of EM wave energy at any point on the x axis is given by the Poynting vector

$$\boldsymbol{S}(x) = \boldsymbol{e}(x)\times\boldsymbol{b}(x)/\mu_0$$

or

$$\boldsymbol{S}(x) = (c/\mu_0)b_0^2(x)\sin^2(\omega t - kx)\boldsymbol{a}_x \qquad (4)$$

where c is the speed of light. It has been shown on straightforward theoretical grounds that there is an *additional* energy flux $\boldsymbol{s}(x) = cu(x)\boldsymbol{a}_x$ that is just as real and as observable as $\boldsymbol{S}(x)$. On assuming for a moment that $\boldsymbol{B}$ is uniform and parallel to $\boldsymbol{b}$, one obtains

$$\boldsymbol{s}(x) = (c/\mu_0)Bb_0\sin(\omega t - kx)\boldsymbol{a}_x. \qquad (5)$$

This is an energy density wave that accompanies the EM wave (and hence the name companion wave), representing a sloshing back and forth of the interaction energy u at the speed of light. There is no net unidirectional propagation of this energy. The electric and magnetic fields of the EM wave remain unaffected, and no additional fields arise. In order to achieve communication in the companion wave mode, however, there must be unidirectional propagation and there must arise new field components. This can be achieved by having the field $\boldsymbol{B}(\boldsymbol{r})$ generated in a localized source region, and by making this field time-varying. The result is a pumping of energy into the companion wave mode.

The conventional radio signal Q may be considered here as being sent through the flux $\boldsymbol{S}$ by making the

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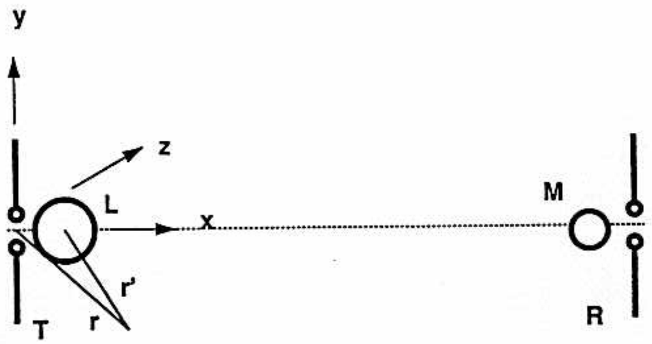

Figure 1. Conceptual arrangement for transmitting and receiving signals in both radio wave and companion wave modes. T and R are transmitting and receiving electric dipole antennas, L is a non-radiating current loop producing an oscillating magnetic field, and M is a magnetic antenna that senses time-varying magnetic fields (not drawn to scale).

amplitude $b_0(x)$ a function of time at the origin, $b_0(0, t)$. The question now arises of whether or not a *different* signal Q' may be sent simultaneously through the flux s by making B a function of time at the point of transmission, $B(0, t)$. To examine this, let a sinusoidally time-varying magnetic field be produced near the origin (at T) in a source volume by a non-radiating current loop L with its axis parallel to the z axis and its centre at $x = a$ in front of the dipole. The term non-radiating means that, at the frequency of operation of the loop and under normal circumstances, the entire EM energy fed to the loop by a generator oscillates between the loop and the generator, with a negligible portion of the energy escaping as the EM wave. The source volume is that approximate volume outside which the magnetic field due to the loop is undetectable. Let l be the linear extent of the source volume (l is about equal to the diameter of the loop), and let $l < \lambda/2$ (see discussion later) and $l \ll D$. Thus, at R there is no measurable magnetic field due to the loop. Since the electric field due to the loop is $E \simeq \nu l B$ (ν is the angular frequency of excitation of the loop), the ratio of the electric and magnetic energy densities is $E_e/E_m \simeq \nu^2/l^2c^2$. Thus, if l is kept much smaller than the wavelength at frequency ν, then the electric field E is unimportant for the present discussion and the energy of the loop is predominantly magnetic energy. The loop magnetic field $\boldsymbol{B}$ is now written as

$$\boldsymbol{B}(\boldsymbol{r}') = \boldsymbol{B}_0(\boldsymbol{r}') \sin(\nu t + \phi) \tag{6}$$

where B_0 is the amplitude, ϕ is a phase angle and $\boldsymbol{r}'$ is referred to the origin shifted to $x = a$. The functional forms of $\boldsymbol{b}_0(\boldsymbol{r})$ and $\boldsymbol{B}_0(\boldsymbol{r}')$ are well known [2]. The resultant interaction energy density is

$$u(\boldsymbol{r}) = \boldsymbol{B}_0(\boldsymbol{r}') \cdot \boldsymbol{b}_0(\boldsymbol{r}) \sin(\omega t - kr) \sin(\nu t + \phi)/\mu_0. \tag{7}$$

Any direct coupling between the antenna and the loop (namely mutual coupling) or scattering of the EM wave by the loop is not included in the present discussion. A simple examination of the magnetic field line geometries shows (as can be verified by numerical integration) that the time-averaged power out of the source volume

$$P = \left\langle \int u(r)\, \mathrm{d}V \right\rangle_T \Big/ T \tag{8}$$

where $T = 2\pi/\nu$, can be made a non-zero positive quantity. Since it has already been established that this energy flow is real and observable, it follows that the energy will propagate *unidirectionally* out to infinity. As this energy travels at the speed of light, the signal Q' (in the form of a modulation of B_0) will arrive at R after a time $t_0 = D/c$, at the same time as the signal Q arrives. Any contribution to P from an $\boldsymbol{E} \times \boldsymbol{b}$ Poynting term is negligible if $B \simeq b$ and $E \ll e$ (see later discussion). There are no known effects that would guarantee that P remain identically zero under all circumstances.

Since the two primary sources of energy in the medium are the EM wave energy and the magnetic energy of the loop and since the EM wavefields remain unaffected by the interaction, it follows that a unidirectional spatial spreading of the interaction energy can occur only if a portion of the magnetic energy in the field of the loop expands in space with time (at the expense of the generator that powers the loop). At R there arises a *propagated* magnetic field (with its associated electric field) from the loop that would not arise in the absence of the EM wave. This is the physical process by which the signal Q' is conveyed. In terms of magnetic field line imagery, one may imagine the field lines due to the loop ballooning out in space in a pulsating fashion.

Since Maxwell's equations are linear, they allow spatial expansion of the energy in the manner described above. The propagated fields $\boldsymbol{B}$ and $\boldsymbol{E}$ at a distance point are what would normally exist if the current in the loop were much stronger. The emergence of these new fields at distant points in space is required by energy conservation. If the presence of these fields is accordingly allowed for, then the principle of superposition of EM fields is not violated: the field at any distant point is the sum of the EM wavefield and the companion wave signal field. For the latter mode of energy propagation, $E \ll cB$ whereas, for the EM wave, $e = cb$. Thus the concept of a wave impedance should not be applied to propagation of the companion wave *signal*.

In the original discussion [1], a static magnetic field existing in the entire region between T and R was assumed to generate a 'carrier' companion wave (see equation (5)) to be modulated by the signal $\boldsymbol{B}$. It is now seen that the static magnetic field is unnecessary, and that the EM wave serves as the carrier for both the EM wave signal and the companion wave signal.

The practical problem of generating a companion wave is a problem of achieving a compromise between maximizing the power P while keeping ν substantially below ω. The latter condition ensures that l is much smaller than the wavelength at the frequency ν, while still $l \leqslant \lambda/2$. The placement of the loop in relation to the electric dipole is an important factor in determining P, and should be outside the near zone (the non-propagation zone) of the dipole. The condition $l \leqslant \lambda/2$ arises from the fact that the field B has to perform work on, or oppose, the field b when the latter is increasing in strength with time over a half-wavelength segments in space.

At the receiving location $x = D$ there arise the EM wavefields

$$b(D,t) = b_0(D,t)\sin(\omega t - kD)\,a_z \tag{9}$$

$$e(D,t) = e_0(D,t)\sin(\omega t - kD)\,a_y \tag{10}$$

and the companion wave signal fields

$$B(D,t) = B_0(D,t)\sin(\nu t + \phi')\,a_z \tag{11}$$

$$E(D,t) = E_0(D,t)\sin(\nu t + \phi')\,a_y \tag{12}$$

where ϕ' is a phase angle, and the signals are contained in the amplitudes (Q in b_0 or e_0, Q' in B_0 or E_0). It should be noted that, while the x-dependence of B and E (included above in its entirety in the amplitudes B_0 and E_0) has a periodicity, this dependence is not necessarily sinusoidal. This dependence is determined by the source mechanism (the integration in equation (8)). The angle ϕ' is also determined by this integration.

The companion wave signal B or E can now be received by conventional antennae, without necessitating a force-measuring antenna. The receiving dipole R will sense the electric fields while a magnetic antenna (shown here as a loop M) will sense the magnetic fields. It will be seen below that $B_0 < b_0$, so that $E_0 \ll e_0$. Thus, the dipole may not experience the signal Q' at all. The loop M will register a superposition of Q and Q'. Knowing Q from the dipole, the two signals can be separated. More conveniently, the disparity between ω and ν may be exploited to receive only Q with dipole, and only Q' with the loop, by tuning or filtering. This disparity may also help any unwanted mutual coupling between T and L.

It has been suggested that the companion wave is observable with present-day technology [1]. The criteria for feasibility of companion wave communication over a given distance D may be developed along the following lines. From simple energy conservation arguments it follows that an estimate for $B_0(D)$ is

$$B_0(D) \simeq B_0(0)F^{1/2}G^{1/2}l/D$$

where G is the gain of the electric dipole and

$$F = P(\nu < \omega)/P(\nu = \omega)$$

is a theoretical efficiency factor (< 1) that can be evaluated numerically. It is now to be noted that the signal field $B_0(0)$ should not exceed the carrier field $b_0(0)$. Assuming that $B_0(0) \simeq b_0(0)$ leads to

$$B_0(D) \sim b_0(D)F^{1/2}$$

which allows one to estimate the strength of the companion wave signal in terms of the known strength of the conventional radio signal. For an order-of-magnitude estimate, one can make simplifying assumptions in equation (8) to obtain

$$\mathrm{O}(F) \simeq \int_0^T \sin(\omega t)\sin(\nu t)\,\mathrm{d}t \Big/ \int_0^T \sin^2(\omega t)\,\mathrm{d}t$$

which is readily evaluated.

The elementary dipole–loop combination was used here to illustrate clearly the physical principles involved. Other antenna types and arrangements may be more suitable in practice. Also, only amplitude modulation was considered. Other types of modulation (phase or frequency) may also be discussed.

Since time-varying magnetic fields at radio frequencies can be detected down to very small values using ordinary conductors (about 10^{-10} T) and, in principle, to arbitrarily low values using superconductors, there do not appear to be any radical barriers in the way of realizing companion wave communication, at least for relatively short distances. It may be that, just as electric aperture antennae (such as the parabolic reflector) made satellite communication and radio-astronomy possible, so will ingeniously conceived 'magnetic aperture antennae' make companion wave communication possible. While one possible application of the suggestion of this communication is that it could expand the signal-carrying capacity of an existing radio link, other beneficial application directions may also be imagined. The question of propagation effects due to the companion wave in a material medium has been touched on elsewhere [3].

References

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