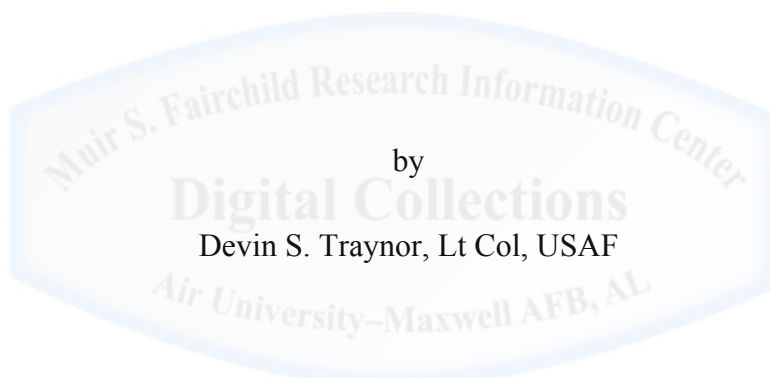


AIR WAR COLLEGE

AIR UNIVERSITY

APPLICATION OF SUPERLUMINAL RADAR
TO MAINTAIN AIR SUPERIORITY IN 2035



A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

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Biography

Lt Col Devin Traynor is assigned to the Air War College, Air University, Maxwell AFB, AL. He earned a BS in Physics from the United States Air Force Academy in 1996, an MS in Aerospace Engineering from the University of Alabama, Tuscaloosa, in 2006, and an MS in Flight Test Engineering from the United States Test Pilot School in 2007. Lt Col Traynor completed two operational tours in the F-15E Strike Eagle at Elmendorf AFB, Alaska, and Seymour Johnson AFB, North Carolina. He instructed Introduction to Fighter Fundamentals in the AT-38B at Moody AFB, Georgia, and served as an Air Force One Presidential Advance Agent for President Bush. After graduating from the United States Air Force Test Pilot School, Lt Col Traynor served as an F-15 developmental test pilot for the 40th Flight Test Squadron and the Chief of Standardization and Evaluation for the 46th Operations Group at Eglin AFB, Florida. He was the Director of Operations and later Commanded the 411th Flight Test Squadron and F-22 Combined Test Force at Edwards AFB, California. A command pilot, Lt Col Traynor has more than 3,000 hours in 47 different aircraft. He led combat missions in Operation NORTHERN WATCH, and served as an Air Advisor to the Iraqi Air Staff during Operations IRAQI FREEDOM and NEW DAWN.

Abstract

Keeping the “first look, first shot, first kill” advantage is essential to maintaining Air Superiority into 2035. Although our adversaries seek to deny us that advantage, this paper shows how a newly realized aspect of physics can allow us to keep the scales balanced in our favor. Physicist James Clerk Maxwell showed that electromagnetic radiation may be created by establishing either a free current or a displacement current in a medium. Since the first application of his theory, we have only exploited the former method to create practical radar systems. We do this by creating a free current in a radar antenna to broadcast electromagnetic radiation toward a target, and then examine the reflections of the radiation from the target. Because of the laws of physics, the energy directed at the target spreads three-dimensionally on its way to the target and back. An adversary aircraft can exploit this spreading loss by transmitting a jamming signal that only spreads over half the distance, since the jamming signal doesn’t need to return to the enemy aircraft. This gives the adversary a fundamental power advantage over the friendly fighter. However, recent research shows that by creating an accelerating superluminal polarization current in an antenna, we can create a new class of electromagnetic wave front that spreads two dimensionally toward the target. This results in more than a one-power increase in burn-through range against a jamming target. Beyond the application for defeating radar jamming, this paper also briefly describes several other applications that individually could be the focus of separate studies, including electronic attack, electronic protection, efficient communications, secure communications, and directed energy weapons.

Introduction

Continuing our ability to target, engage, and destroy air-to-air targets at long range is a key cornerstone of Air Superiority. The F-22 Raptor slogan “First look, first shot, first kill” captures the reality that in today’s air fight, the victor is usually the aircraft that sees its adversary and is able to shoot first. In fact, one of the fundamental advantages any fifth-generation fighter has over its adversary is its stealth, which decreases the range at which an adversary can target and engage it. As long as the friendly fighter is able to kill the enemy before it is able to engage, the friendly fighter enjoys an asymmetric advantage in gaining and maintaining Air Superiority.

Unfortunately, modern adversaries have an asymmetric counter at their disposal—physics. Because of the laws of physics, in today’s offensive air-to-air fight the enemy always has a power advantage when it comes to jamming. Left unchecked, this asymmetry is significant enough to tip the scales completely in favor of the adversary. Of course we don’t let it go unchecked, but instead invest significant time, money, and manpower to stay ahead of enemy jamming techniques; but it is an uphill battle—one that constantly threatens our Air Superiority.

Thesis

Fortunately, the laws of physics may offer an asymmetric counter to the adversary’s counter measures. Cutting-edge research has led to a new class of antenna that emits electromagnetic radiation in an unusual way, producing a component of the radiation whose power falls off more slowly with distance than that from a conventional antenna.¹ This paper investigates some of the advantages of this new class of antenna, with explanations intended for readers with a non-technical background; however, it also lays out the math behind these explanations for readers desiring a more rigorous understanding of the physics involved.

Overall, this paper explains the basic physics behind electromagnetic radiation, how it makes a traditional radar work while at the same time making it vulnerable to jamming, and how a newly realized implementation of the laws of physics will allow us to tip the scales back in our favor. Before concluding, it briefly presents an overview of other applications that could individually be the focus of future independent studies. The goal is to consider areas where we should focus investment to ensure United States dominance and Air Superiority into 2035.

Background

RADAR, as it is more commonly referred to, is a method of using electromagnetic radiation to determine the precise position and velocity of distant objects. At the most basic level, it involves generating and directing an electromagnetic wave toward an object and measuring how long it takes for a reflected wave to return to the sender. The first applications of radar used electromagnetic radiation in the radio portion of the electromagnetic spectrum—hence its name. However, the theory is applicable to radiation across the electromagnetic spectrum. Because radar developers learned they could get better time resolution with shorter wavelengths, modern radars typically use shorter wavelength radiation in the microwave and the very-high-infrared portions of the electromagnetic spectrum. The term radar has simply grown to encompass this portion of the spectrum as well.²

Maxwell's Equations

Scottish physicist James Clerk Maxwell began shaping our understanding of the basic physics behind radar theory in 1873, more than 50 years prior to its first application.³ He built upon the work of English physicist, Michael Faraday, who demonstrated in the early 1800s that

an electric current produces a magnetic field, and that when the current is stopped, the changing magnetic field induces a current back in the circuit.⁴ Maxwell generalized Faraday's observation by the equation

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad (1)$$

where \mathbf{E} is the electric field and \mathbf{B} is the magnetic field.⁵ (Note: the bold letters designate these are vector fields, which means they have both magnitude and direction). This equation essentially says the curl of an electric field, or the measure of its changing direction along a curved path about a point, is equal to the negative rate of change of the magnetic field. ($\nabla \times \mathbf{E}$ is the cross product of the differential "del" operator and the electric field vector). In simpler terms, it captures the fact that a changing magnetic field generates an electric field (as in a generator).

To further develop the physics behind radar, Maxwell also built upon the work of French physicist and mathematician, André-Marie Ampère. Ampère discovered that a steady flowing current produces a magnetic field expressed by the equation

$$\nabla \times \mathbf{B} = \mu \mathbf{J} \quad (2)$$

where again \mathbf{B} is the magnetic field, \mathbf{J} is the current density of free charge carriers, and μ is a constant known as the magnetic permeability, which is specific to the material in which the magnetic field is induced.⁶ This equation says the curl of a magnetic field, or the measure of the infinitesimal rotation of its associated vector field about a point, is proportional to the density of the current flowing through the point. Put more simply, it says a flowing current creates a magnetic field (as in a motor).

Maxwell discovered a problem with Ampère's equation, however, by recognizing equation 2 is only valid for steady currents.⁷ This is easiest to understand numerically: a

fundamental vector identity states the divergence of the curl is always zero for any vector field.

This is expressed by the equation

$$\nabla \cdot (\nabla \times \mathbf{V}) = 0 \quad (3)$$

where \mathbf{V} represents any vector field.⁸ If we take the divergence of both sides of equation 2 we get

$$\nabla \cdot (\nabla \times \mathbf{B}) = \nabla \cdot \mu \mathbf{J} \quad (4)$$

and substituting the left side of this equation with the vector identity from equation 3, we get

$$0 = \nabla \cdot \mu \mathbf{J} \quad (5)$$

Fundamentally, equation 5 says the divergence of any current density is always zero, which means the electric current flowing into a region is always equal to the electric current flowing out of the region. While this seems reasonable when you consider current flowing into a segment of wire is equal to the current flowing out of that segment of wire, Maxwell knew it breaks down when you consider an alternating current circuit containing a capacitor, such as depicted in figure 1.

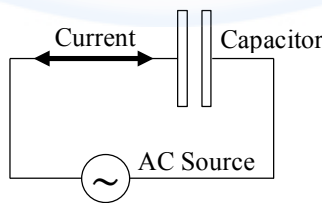


Figure 1: Alternating current circuit with a capacitor⁹

Because a capacitor is essentially two flat plates separated by an insulating material, free-current cannot flow through it. Equation 5 implies that since no current is leaving one flat plate into the insulating material, no current should flow into the other flat plate and to the wire.

Experimentally, however, it is easy to measure that a current does indeed flow through the circuit even though no current flows through the gap that is the capacitor.¹⁰

Maxwell remedied this inconsistency by recognizing that even though no current flows through the gap, the electric field between the plates and the current charge density within them does change. Just as Faraday's equation describes how a changing magnetic field gives rise to an electric field, Maxwell reasoned that the changing electric field and charge density should contribute to the magnetic field in Ampère's equation (2). He added a term he called the displacement current density (\mathbf{J}_d) to Ampère's equation to account for this:

$$\mathbf{J}_d = \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \frac{\partial \mathbf{P}}{\partial t} \quad (6)$$

Here, ϵ_0 is a constant called the electric permittivity of free space, similar the magnetic permeability introduced in equation 2, and \mathbf{P} is the polarization current that accounts for the changing charge density on the plates of the capacitor. Added to Ampère's equation, the new equation, which has become known as Maxwell's fourth equation, or the Ampere-Maxwell equation, is given by

$$\nabla \times \mathbf{B} = \mu \mathbf{J} + \mu \mathbf{J}_d \quad (7)$$

or substituting in the displacement current density from equation 6

$$\nabla \times \mathbf{B} = \mu \mathbf{J} + \mu \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mu \frac{\partial \mathbf{P}}{\partial t} \quad (8)$$

This insight allowed Maxwell to unify Ampère's law and Faraday's law. By solving these coupled differential equations (2 and 8), he showed for the first time that varying electric and magnetic fields couple to each other in a wave-like manner that allows them to propagate indefinitely through space at exactly the speed of light.¹¹

Classic Radar Theory

The generation of electromagnetic radiation as it pertains to classic radar theory is fully described by Maxwell's fourth equation (8). By introducing a current through the $\mu \mathbf{J}$ term of this

equation in an antenna element, radar engineers create an electromagnetic wave that can be directed to and reflected off a target. Knowing the speed at which the wave propagates through the space between the transmitter and the target (the speed of light), the round-trip distance is calculated as the rate at which the signal travels times the time it takes for the signal to return to the transmitter. The distance to the target is just half this distance. The angular direction to the target is simply the opposite of the direction from which the reflected signal returned.

While Maxwell's equation predicts an electromagnetic signal will self-propagate indefinitely through free space, there are practical limits to its range in the atmosphere. This is because at its heart, radar relies not just on transmitting a signal, but receiving the reflected signal from the target and distinguishing it from the background noise in nature and the radar itself. The situation is analogous to trying to hold a conversation in a loud room: if the ratio of the signal (the conversation) to the background noise is too low, the signal is lost in the noise. In radar systems, the signal and noise are measured in terms of power. Thus, if the ratio of the signal power to the noise power (S/N ratio) is too low, the signal is indistinguishable from the noise.¹²

The power a radar receives from a target is governed by three factors: the average power, or rate of flow of energy radiated in the target's direction; the fraction of power that scatters off the target back in the radar's direction; and the fraction of the power the receiving antenna captures.¹³ To determine the first two, we have to account for the energy lost in the space between the radar and the target due to atmospheric absorption and geometric spreading.¹⁴ Atmospheric absorption is negligible in the microwave portion of the spectrum where modern radars operate (on the order of one hundredth of a decibel attenuation per kilometer) and can be ignored.¹⁵ Geometric spreading, however, causes a significant reduction in power. By

definition, conventionally generated electromagnetic energy from an ideal isotropic¹⁶ source spreads evenly in all three dimensions; thus the power is distributed evenly over a spherical surface area at any given distance from the transmitter. Since the surface area of a sphere of radius R is $A = 4\pi R^2$, the power density at that radius from the source is reduced by

$$P = \frac{P_{avg}}{4\pi R^2} \quad (9)$$

where P_{avg} is the average transmitted power. To account for the directionality of a non-isotropic antenna that does not radiate evenly in all directions, a gain factor G is added making the power density of the signal at the target¹⁷

$$P = \frac{P_{avg}G}{4\pi R^2} \quad (10)$$

Only a fraction of the energy that makes it to the target is reflected back in the direction of the receiver. This fraction is determined by the target's geometric cross-sectional area (how big the target is), its reflectivity (how much energy it reflects), and its directivity (how much of the reflected energy is in a direction toward the receiver). These are typically lumped into a single factor representing the effective reflecting area called the radar cross-section, or σ .¹⁸ Because this energy has to travel back to the receiving antenna, it is subject to the same geometric spreading across another distance R , and thus the power density that arrives back at the receiver is further reduced by a factor

$$P = \frac{\sigma}{4\pi R^2} \quad (11)$$

Multiplying equations 10 and 11 yields the total power density the receiver sees after the original signal travels to the target and back. Multiplying by a gain factor (A_e) to account for the effective area of the receiving antenna, the total power the receiver sees is¹⁹

$$P_R = \frac{P_{avg}G}{4\pi R^2} \cdot \frac{\sigma A_e}{4\pi R^2} = \frac{1}{(4\pi)^2} \frac{P_{avg}G\sigma A_e}{R^4} \quad (12)$$

An important thing to note here is as the range to the target increases, the signal energy the receiver has to work with decreases proportionally to a factor of $\frac{1}{R^4}$. This means as the range to the target increases, the signal to noise ratio decreases exponentially and the signal is quickly lost in the background noise.

Radar Jamming

A target that doesn't want to be seen can exacerbate the problem for the radar by jamming its signal. Jamming involves transmitting electromagnetic radiation in the direction of the radar to make it more difficult for the radar to distinguish the actual signal. This can be done by simply transmitting noise designed to decrease the S/N ratio for the radar, or can involve more complex techniques designed to make the radar process false signals instead of the actual reflected signal. Regardless of the technique, whether it is basic noise jamming or the most advanced digital radio frequency memory (DRFM) jamming, effective jamming relies on preventing the radar from identifying the real signal return.²⁰

The most common way to describe the effectiveness of a jammer is in terms of the ratio of the effective jamming power to the signal power that makes it to the radar.²¹ Similar to the signal to noise (S/N) ratio, the jamming to signal (J/S) ratio measures how difficult it is for the radar to see the actual signal. The higher the J/S ratio, the more difficult it is for the radar to see the real signal. Depending on the technique the jammer uses and the sophistication of the radar, the J/S ratio required for effective jamming can be as little as 0 dB or as much as 40 dB or more.²² Regardless of the actual threshold for effective jamming, below the threshold the radar will see the target, and above the threshold the radar will see the jamming.

The jamming power the radar sees is governed by the same factors that determine the signal power the radar sees, except instead of having to make a round trip, the jamming signal only travels the distance between the target and radar once. Thus, after accounting for geometric spreading and taking the jamming and receiving antenna gains into account as before, the jamming power the radar sees (P_{JR}) is

$$P_{JR} = \frac{P_J G_J A_e}{4\pi R^2} \quad (13)$$

where P_J is the average power of the jammer, G_J is the gain due to directionality of the jammer's antenna, and A_e is the effective antenna area of the radar receiver.

The important thing to note here is unlike the radar signal that decreases as the 4th power of the distance between the radar and target, the jamming signal decreases as the 2nd power of that distance. This means even a relatively low-power jammer has an advantage over the radar until the target and radar are close enough that the energy from the reflected signal exceeds the minimum detection threshold to be distinguishable from the jamming signal. That point is known as the burn-through range and is depicted in figure 2 for a notional case.²³

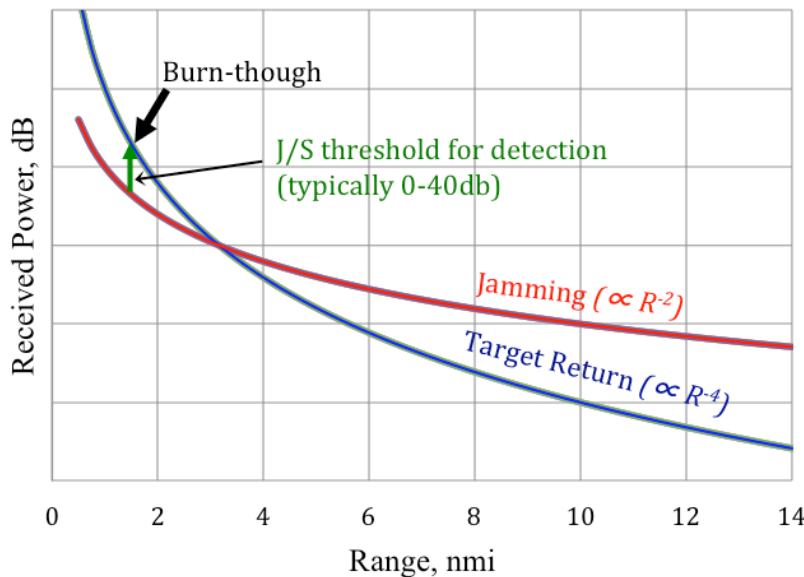


Figure 2: Radar burn-through range²⁴

If we take the ratio of the jamming power to the signal power (equations 12 and 13) we get

$$J/S = 4\pi R^2 \frac{P_J G_J}{P_{avg} G \sigma} \quad (14)$$

Then, setting J/S equal to the detection threshold and solving for the burn-through range, we get

$$R_{BT} = \sqrt{\frac{1}{4\pi} \cdot \frac{P_{avg} G \sigma}{P_J G_J} \cdot J/S_{detect}} \quad (15)$$

The important thing to note is that to maintain the first-look, first-shoot advantage, we need R_{BT} to be as large as possible.

Antennas Employing Accelerated Superluminal Polarization Currents

With a conventional radar, equation 15 shows the only way to increase the burn-through range is to increase the power output, increase the gain of the radar antenna, or increase the radar's ability to distinguish the actual signal from the jamming signal (increase J/S_{detect}). New theory describes another way to create a burn-through advantage—using superluminal radiation sources.

All the radar theory discussed up to this point is possible because we are able to create electromagnetic radiation by manipulating the current density (\mathbf{J}) in Maxwell's equation (8):

$$\nabla \times \mathbf{B} = \mu \mathbf{J} + \mu \epsilon \frac{\partial \mathbf{E}}{\partial t} + \mu \frac{\partial \mathbf{P}}{\partial t} \quad (8)$$

But Maxwell predicted we can also manipulate the displacement current to create electromagnetic radiation. Specifically, by creating a time-varying polarization (\mathbf{P}) in a material, the $\frac{\partial \mathbf{P}}{\partial t}$ term in equation 8 contributes to the creation of a magnetic field (\mathbf{B}) just as the free-electron current (\mathbf{J}) does. Practically, we may accomplish this by subjecting a dielectric material to an electric field. Unlike a conducting material where the electrons are free to move, the

electrons in a dielectric are bound at the atomic level, but can move locally to align with the electric field. If the electric field is applied in such a way that neighboring elements of the dielectric are polarized and then depolarized successively in a linear fashion, we can create a polarization current that generates electromagnetic radiation just as if a free-electron current were flowing through the material.

The mechanics behind the polarization current is analogous to the “wave” spectators sometimes create at sporting events by successively standing up and then sitting down at coordinated times. The individual spectators can be thought of as discrete segments of the dielectric, where a standing spectator is a polarized element, and a sitting spectator is a non-polarized element. By successively standing and sitting at the appropriate time, the spectators create a visible wave that travels rapidly around the stadium. While the individual spectators only move locally, and their actual motion is relatively slow, the wave they create may travel quite rapidly around the stadium.²⁵

The interesting thing about a wave created in this fashion is that there is practically no limit to its speed. The only limiting factor to the speed becomes how precisely you can coordinate the timing delay of the polarization between successive elements, and the speed of the resulting wave only depends on the distance between the elements and that delay. In fact, if the delay is small enough, it is even possible to create a polarization current “wave” that travels faster than the speed of light. On the surface this may seem to violate Einstein’s theory of special relativity, which states that any particle with a resting mass cannot be accelerated to or beyond the speed of light; however, since the wave is really just the observed effect of the much smaller local movements of electrons in the dielectric, it does not violate special relativity.²⁶

Between 2004 and 2007, in collaboration with H. Ardavan of the University of Cambridge, British physicist Dr. John Singleton conducted experimentation sponsored by the Los Alamos National Laboratory to demonstrate the feasibility of creating electromagnetic radiation with superluminal (faster than light in a vacuum) polarization currents. Together, they created a proof-of-principle apparatus at Oxford University.²⁷ Their device, depicted in figure 3, consisted of a 10-degree arc of a 10.035 m radius circle of dielectric alumina material (aluminum oxide—the white strip at the right side of the photo).

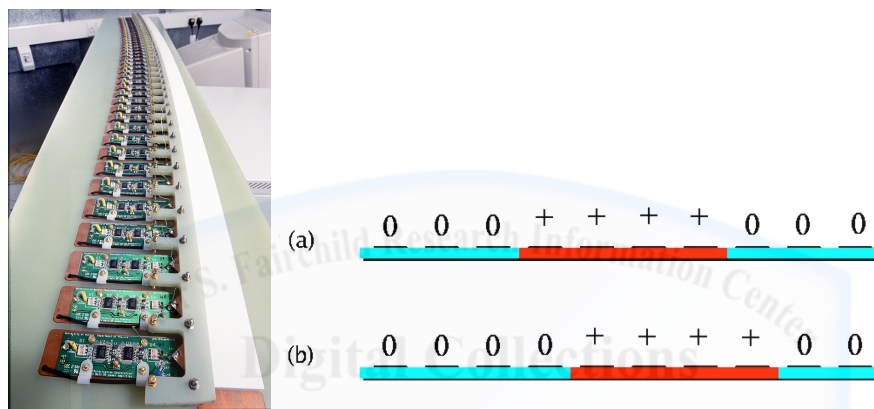


Figure 3: Superluminal source built at Oxford University²⁸

To the left of the alumina arc, an array of amplifier driven electrodes were spaced evenly and connected to the dielectric. At time t (a), a voltage applied to some of the elements created a polarization in the dielectric. At time $t + \Delta t$ (b), one electrode was switched off and another switched on to create a moving polarization current.²⁹

Not only did this experiment prove it is possible to create electromagnetic radiation through superluminal polarization currents, it showed such radiation exhibits fundamentally different characteristics than traditionally generated electromagnetic radiation. Specifically, the experiment demonstrated a radiation source that exceeds its own wave velocity (the speed of light) creates a sort of shock wave, similar to the shock wave created by a supersonic airplane

when it acts as a source of sound that exceeds its own wave velocity (the speed of sound). This leads to a situation where multiple waves emitted at different time may arrive at an observer at the same time, reinforcing each other.³⁰ We can intuitively visualize this by considering Huygens wavelets emitted from the source:

In 1690, mathematician Cristiaan Huygens showed the propagation of light could be thought of as individual wavelets radiating from a source in all directions, and that as they propagate, each wavelet itself becomes a subsequent source of wavelets radiating in all directions. The net effect is the leading wavelets add up to create a wave front, and each point on the wave front represents a subsequent source of spherical wavelets. This is depicted in figure 4.³¹

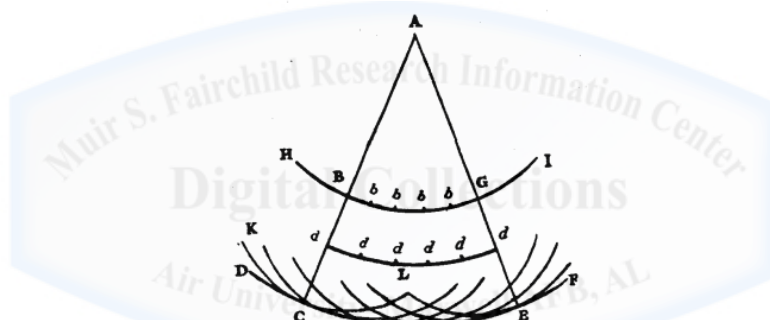


Figure 4: Huygens wavelets³²

Here, A is the original source, and the arc DF is the wave front made up of the contributions from the wavelets emitted along a previous wave front arc HI.

If the source is moving faster than the individual wavelets, it is able to get out ahead of them as depicted in figure 5.

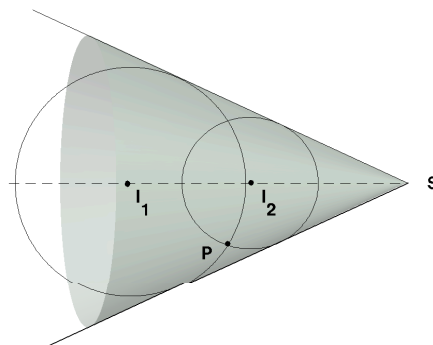


Figure 5: Huygens wave front for a superluminal source³³

Here, the source S is in front of all its wavelets. In the time it took for the source to travel from point I_1 to S , the wave front of the wavelets emitted at I_1 has propagated the distance of the circle around I_1 . Similarly, in the time it took for the source to travel from point I_2 to S , the wave front of the wavelets emitted at point I_2 has propagated the distance of the circle around I_2 . In the snapshot of time depicted, the wave fronts from both points arrive at a stationary observer P at the same time, even though they were emitted from the source at different (retarded) times. In this way, the single wave front the observer sees is stronger than actual wave front emitted from the source since what the observer sees is a superposition of multiple wave fronts emitted at different retarded times.

Adding up all the previously emitted wavelets forms a cone behind the source. In the case where the source is supersonic and the emissions are sound, we call this cone a Mach cone, in honor of polymath Ernst Mach who first described these conical wave fronts (he called them shockwaves) generated by supersonic bullets. Similarly, in the case where the source is superluminal and the emissions are electromagnetic radiation, we get a conical wave front called a Čerenkov envelope, in honor of the Soviet physicist Pavlov Čerenkov who won the Nobel Prize in 1958 for discovering the radiation from these wave fronts emitted by charged particles travelling faster than the speed of light in a medium such as water.³⁴ In either case, an observer outside the cone will be unaware the source has traveled past his position until the expanding cone reaches him. When it does, the observer will experience a single reinforced wave front traveling orthogonally to the cone.

If, instead of propagating at a constant superluminal velocity, the polarization current accelerates, the wavelet interaction creates a more interesting pattern.

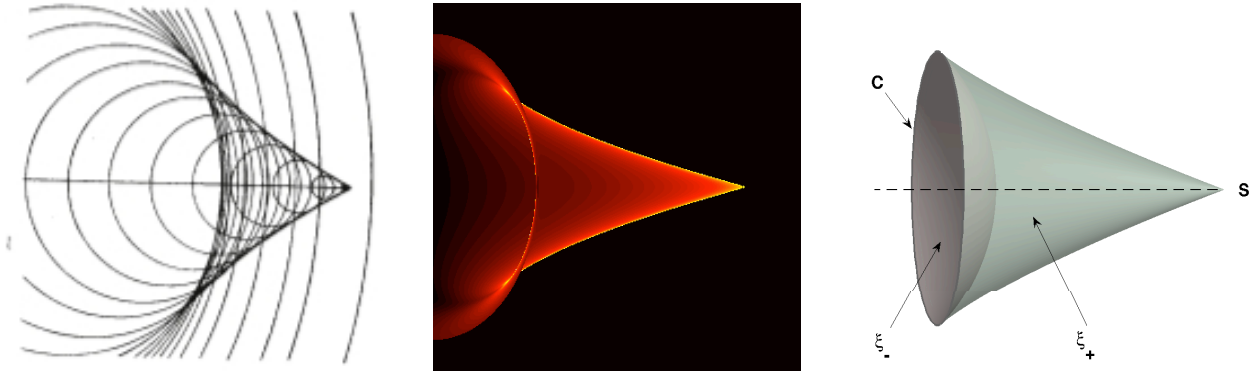


Figure 6: Linearly accelerating superluminal source (left and middle: 2D; right: 3D)³⁵

Figure 6 depicts an accelerating source. On the left and center, the source starts subluminal. As it transitions to superluminal, it begins passing previous waves, and instead of a straight cone, the wave front takes on a concave conical shape.³⁶ The picture on the right depicts the wave fronts emitted, which consist of two axisymmetric sheets (ξ_+ and ξ_-) that meet to form a cusp (C). The cusp is a region of intensely concentrated radiation built up from the emissions from an extended period of retarded time.³⁷ Essentially, the radiation from the source is focused at a distance as if from a lens or mirror; however, the focusing here is in the time domain and is referred to as “temporal focusing.”³⁸ In the analogous case of a linearly accelerating supersonic aircraft, this same situation leads to an extra-loud sonic boom, sometimes referred to as a “superboom.”³⁹

An even more interesting effect occurs if the radiation source accelerates centripetally (versus linearly). Figure 7 (left and center) shows the top-down view of the resulting cusp (the line spiraling out from the point C) for a point charge (S) in constant superluminal rotation. The diagram on the right shows the side view of the same cusp spiraling out above and below the plane of rotation.⁴⁰ Interestingly, the intensity of the radiation in the cusp region drops off as $1/R$ (distance), leading to very efficient long-distance propagation.⁴¹

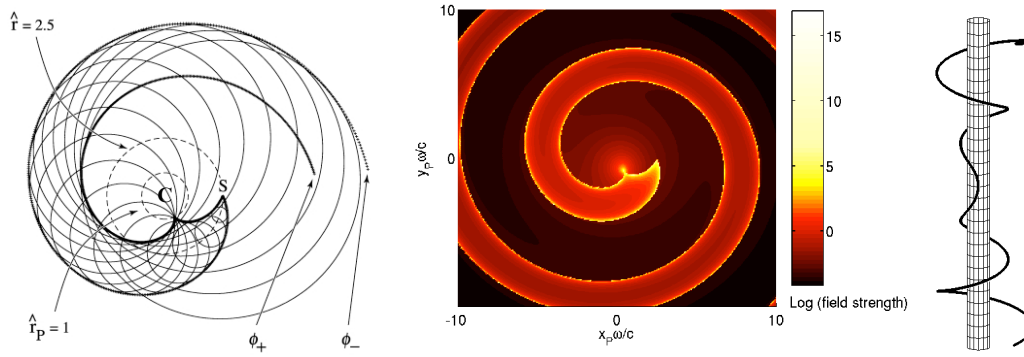


Figure 7: Centripetally accelerating superluminal source⁴²

Thus, just as we derived equation 10 to describe the geometric spreading of the power from a conventional source, we can derive an equivalent equation to describe the geometric spreading of power from the cusps of a circular superluminal source. Since the surface area of the cusp increases proportional to the distance, the power density at a radius R from the source is reduced by

$$P = \frac{P_{avg} G_s}{\alpha R} \quad (16)$$

where P_{avg} is the average transmitted power and G_s is a gain factor that accounts for the directionality of the superluminal antenna and temporal focusing, and α is a proportionality constant that accounts for the effective area over which the radiation spreads.⁴³ Experimental data from a working prototype (figure 8) at the Los Alamos National Laboratory confirm these predictions and show the direction of the emitted “beam” depends only on the speed of the source, the beaming is frequency independent and so could be used to direct multiple beams at different frequencies, and the energy from the superluminal component of the wave front spreads proportionally to $\frac{1}{R}$ away from the source.⁴⁴

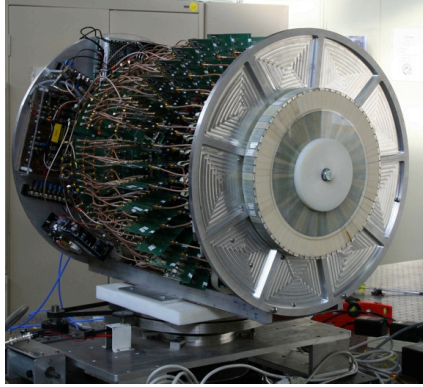


Figure 8: Centripetally accelerating superluminal demonstrator at Los Alamos⁴⁵

Superluminal Radar Versus a Jamming Target

Having derived the basics of classical radar and jamming theory, as well as having described the radiation a superluminal antenna creates, we'll now merge the two and consider the effects of using a superluminal radar against a jamming target. Recall from equations 12 through 15 that the reflected radar power and the jamming power a conventional radar receiver sees respectively, as well as the J/S ratio and burn-through range are given by

$$P_R = \frac{P_{avg}G}{4\pi R^2} \cdot \frac{\sigma A_e}{4\pi R^2} = \frac{1}{(4\pi)^2} \frac{P_{avg}G\sigma A_e}{R^4} \quad (12)$$

$$P_{JR} = \frac{P_J G_J A_e}{4\pi R^2} \quad (13)$$

$$J/S = 4\pi R^2 \frac{P_J G_J}{P_{avg}G\sigma} \quad (14)$$

$$R_{BT} = \sqrt{\frac{1}{4\pi} \cdot \frac{P_{avg}G\sigma}{P_J G_J} \cdot J/S_{detect}} \quad (15)$$

If, instead, we consider a superluminal antenna transmitting with the same average power, and we conservatively assume the gains are the same, the jamming power the radar sees remains unchanged, however the radar power reflected back from the target becomes

$$P_s = \frac{P_{avg}G}{\alpha R} \cdot \frac{\sigma A_e}{4\pi R^2} = \frac{1}{4\pi\alpha} \frac{P_{avg}G\sigma A_e}{R^3} \quad (17)$$

(the subscript s denotes the equation applies to the power from a superluminal antenna).

Dividing equation 13 by equation 17, the J/S ratio for a superluminal radar transmitter becomes

$$J/S_s = \alpha R \frac{P_J G_J}{P_{avg} G \sigma} \quad (18)$$

Solving for the burn-through range we get

$$R_{BT_s} = \frac{1}{\alpha} \cdot \frac{P_{avg} G \sigma}{P_J G_J} \cdot J/S_{detect} \quad (19)$$

Comparing the burn-through range for a conventional radar (15) to the burn-through range for a superluminal radar, we find equation 19 is equivalent to

$$R_{BT_s} = \frac{4\pi}{\alpha} R_{BT}^2 \quad (20)$$

Essentially, what this means is an aircraft using a superluminal radar will be able to target and engage a jamming adversary at a distance in excess of one power further than an aircraft with a conventional radar. This fact alone tips the scales back in favor of the friendly fighter and helps maintain his asymmetric advantage over the enemy.

Other Applications

While this paper focused specifically on the application of superluminally generated electromagnetic radiation for defeating radar jamming, there are several other applications worth mentioning that individually could be the focus of separate studies; these include electronic attack, electronic protection, efficient communications, secure communications, and directed energy weapons.⁴⁶ Just as we showed the burn-through range could be increased by employing a superluminal radar, an adversaries burn-through range could be conceivably decreased for electronic attack purposes by employing a superluminal jammer. Conversely, in the realm of electronic protection, theoretical predictions and experimental measurements show the phase

fronts from a superluminal source could be made so complex it would be almost impossible for an adversary to synthesize a rogue reflection such as modern DRFM jammers create.⁴⁷ Because the energy emitted by a superluminal source spreads less over distance, more efficient communications transmitters could be created for terrestrial and space applications. This would equate to lower power requirements for longer-range communication and could reduce size and weight requirements. Additionally, predictions show conservation of energy is maintained during temporal focusing because regions of focusing are accompanied by regions of reduced signal energy elsewhere.⁴⁸ Engineers could exploit this phenomenon to develop secure communication systems by producing a signal such that potential eavesdroppers are located in a “null” where the signal energy is zero, or at least undetectable. Finally, physicists at Los Alamos, Oxford, and Cambridge have successfully produced tightly-beamed monochromatic microwave radiation, and predict the ability to produce radiation with frequencies in the terahertz range and beyond using superluminal sources.⁴⁹ Weapon developers could use this capability to enhance existing directed energy weapons such as the Counter-electronics High-powered Microwave Advanced Missile Project (CHAMP), or to create new directed energy weapons, with all the aforementioned superluminal advantages.⁵⁰

Conclusion

Keeping the “first look, first shot, first kill” advantage is essential to maintaining Air Superiority into 2035. Although our adversaries seek to deny us that advantage, this paper shows how a newly realized aspect of the laws of physics can allow us to keep the scales balanced in our favor. Physicist James Clerk Maxwell showed that electromagnetic radiation may be created by establishing either a free current or a displacement current in a medium.

Since the first application of his theory, we have only exploited the former method to create practical radar systems. We do this by creating a free current in a radar antenna to broadcast electromagnetic radiation toward a target, and then examine the reflections of the radiation from the target. Because of the laws of physics, the energy directed at the target spreads three-dimensionally on its way to the target and back. An adversary aircraft can exploit this spreading loss by transmitting a jamming signal that only spreads over half the distance, since the jamming signal doesn't need to return to the enemy aircraft. This gives the adversary a fundamental power advantage over the friendly fighter. However, recent research shows that by creating an accelerating superluminal polarization current in an antenna, we can create a new class of electromagnetic wave front that spreads two dimensionally toward the target. This results in more than a one-power increase in burn-through range against a jamming target. While superluminal research is still in its infancy, it is important that we invest in it now to maintain Air Supremacy moving forward toward 2035.

Notes

¹ Dr. John Singleton (Los Alamos National Laboratory), in discussion with the author, 5 February 2016.

² “Radar.” *Institute of Physics*, (2011): 1,
http://www.iop.org/publications/iop/2011/file_47456.pdf.

³ Ibid., 3.

⁴ Daniel Fleisch, *A Student's Guide to Maxwell's Equations* (Cambridge, NY: Cambridge University Press, 2008), 70.

⁵ Chen Ning Yang, “The Conceptual Origins of Maxwell's Equations and Gauge Theory,” *Physics Today* 67(11), no. 45 (2014): 45-47.

⁶ Fleisch, *A Student's Guide*, 104.

⁷ Raymond A. Serway, *Physics for Scientists and Engineers with Modern Physics*, 3rd ed. (Philadelphia: Saunders College Publishing, 1992), 842.

⁸ George B. Thomas, Jr and Ross L. Finney, *Calculus and Analytic Geometry*, 7th ed. (Reading, MA: Addison-Wesley Publishing Company) A-47.

⁹ Diagram drawn by author based on: Fleisch, *A Student's Guide*, 92.

¹⁰ Fleisch, *A Student's Guide*, 91-92.

¹¹ Andrea C. Schmidt, “Terrestrial and Extraterrestrial Radiation Sources that Move Faster than Light.” (MS Thesis, University of New Mexico, 2006), 15. Interestingly, the speed of light turns out to be given exactly by $\frac{1}{\sqrt{\epsilon_0 \mu_0}}$, where ϵ_0 and μ_0 are the electric and magnetic permeability of free space respectively.

¹² George W. Stimson, *Airborne Radar* (Raleigh, NC: SciTech Publishing, Inc., 1998), 116.

¹³ Ibid., 122.

¹⁴ Ibid.

¹⁵ Ibid., 139.

¹⁶ An ideal isotropic source is a hypothetical representation of a classical radar model that assumes the radar's radiation spreads evenly in all three dimensions.

¹⁷ Naval Air Warfare Center Weapons Division (NAWCWD) TP 8347, *Electronic Warfare and Radar Systems Engineering Handbook*, October 2013, 3-1.2.

¹⁸ Stimson, *Airborne Radar*, 122.

¹⁹ Ibid., 148.

²⁰ For more information about DRFM see S. J. Roome, “Digital Radio Frequency Memory”, *Electronic & Communication Engineering Journal*, August 1990.

²¹ David Adamy, *EW 101: A First Course in Electronic Warfare* (Norwood, MA: Artech House, Inc., 2001), 182.

²² *Ibid.*, 188.

²³ Stimson, *Airborne Radar*, 442.

²⁴ Diagram drawn by author based on: Stimson, *Airborne Radar*, 442. Here, the length of the green arrow represents the J/S decibel difference between the target return signal (blue line) and the jamming signal (red line) required for burn-through. The location on the range axis where the green arrow fits between the red and blue lines corresponds to the burn-through range.

²⁵ Schmidt, "Terrestrial and Extraterrestrial Radiation," 18.

²⁶ A. Ardavan, W. Hayes, J. Singleton, H. Ardavan, J. Fopma, and D. Halliday, "Experimental observation of nonspherically-decaying radiation from a rotating superluminal source" *Journal of Applied Physics*, no. 96, 4614 (2004); no. 96, 7760(E) (2004), 7760.

²⁷ John Singleton, "Construction and Use of Superluminal Emission Technology Demonstrators with Applications in Radar, Astrophysics, and Secure Communications," Eighteen-Month Report on LDRD 20080085 DR (Los Alamos, NM: Los Alamos National Laboratory), 5.

²⁸ Photo and diagram reproduced with permission of the author from: Singleton, "Construction and Use of Superluminal," 6.

²⁹ Singleton, "Construction and Use of Superluminal," 6.

³⁰ Schmidt, "Terrestrial and Extraterrestrial Radiation," 26.

³¹ Christiaan Huygens, *Traité de la Lumière* (Leyden, 1690), trans. S. P. Thompson, *Treatise on Light* (Macmillan, London, 1912), 19.

³² Diagram reproduced from: Huygens, *Treatise on Light*, 19.

³³ Diagram reproduced with permission of the author from: Schmidt, "Terrestrial and Extraterrestrial Radiation," 10.

³⁴ Alexander E. Chudakov, "Obituary: Pavel Alexeyevich Cherenkov," *Physics Today* 45, no. 12 (December 1992): 107.

³⁵ Diagrams reproduced with permission of the authors from: Schmidt, "Terrestrial and Extraterrestrial Radiation," 27, and Singleton, "Construction and Use of Superluminal," 44.

³⁶ Schmidt, *Terrestrial and Extraterrestrial Radiation*, 14.

³⁷ *Ibid.*, 31.

³⁸ Dr. John Singleton (Los Alamos National Laboratory), in discussion with the author, 10 February 2016.

³⁹ H. S. Ribner, "Supersonic Turns Without Superbooms," Technical Note No. 174 (University of Toronto Institute for Aerospace Studies, February 1972), 1.

⁴⁰ Schmidt, *Terrestrial and Extraterrestrial Radiation*, 37, 70.

⁴¹ Dr. John Singleton (Los Alamos National Laboratory), in discussion with the author, 10 February 2016.

⁴² Diagrams reproduced with permission of the authors from: Singleton, “Construction and Use of Superluminal,” 7, 48, and Schmidt, Terrestrial and Extraterrestrial Radiation, 37.

⁴³ Dr. John Singleton (Los Alamos National Laboratory), in discussion with the author, 10 February 2016.

⁴⁴ Ardavan, “Experimental observation of nonspherically-decaying,” 7771.

⁴⁵ Photo provided by Dr. John Singleton (Los Alamos National Laboratory), 10 February 2016.

⁴⁶ Singleton, “Construction and Use of Superluminal,” 5.

⁴⁷ John Singleton, Houshang Ardavan, and Arzhang Ardavan. “United States Patent: 0039324 - Apparatus and Method for Phase Fronts Based On Superluminal Polarization Current”, February 18, 2010, 1.

⁴⁸ Schmidt, Terrestrial and Extraterrestrial Radiation, 99.

⁴⁹ J Singleton, A. Ardavan, H. Ardavan, J. Fopma, D. Halliday, and W. Hayes. *Experimental Demonstration of Emission from a Superluminal Polarization Current – A New Class of Solid-State Source for MHz-THz and Beyond*, Conference Digest of the 2004 Joint 29th International Conference on Infrared and Millimeter Waves and 12th International Conference on Terahertz Electronics (IEEE Cat. No 04EX857, 2004), 1.

⁵⁰ Jason D. Ellis, “Directed-Energy Weapons: Promise and Prospects.” (Washington, DC: Center for a New American Security, April 2015), 22.

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- ⁸ Naval Air Warfare Center Weapons Division (NAWCWD) TP 8347. *Electronic Warfare and Radar Systems Engineering Handbook*. October 2013.
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