Protecting Satellites and Ground Stations from EMP and CME

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Editor

A catastrophic electromagnetic pulse (EMP) or severe solar coronal mass ejection event (CME) could put an end to amateur radio satellite operation as we know it, among other things. Even less severe EMP and CME events can cause significant damage that might require days, weeks or even months to repair. The challenge facing amateur radio satellite operators is how best to protect our radio stations and satellites from significant damage or loss.

The concern for satellite operators is less about taking an extended hiatus from our amateur radio satellite hobby than about the key role amateur radio plays in disaster-related auxiliary communications. This role is the mission focus of the Amateur Radio Emergency Service® (ARES), Radio Amateur Civil Emergency Service (RACES), Military Auxiliary Radio System (MARS), and the Salvation Army Team Emergency Radio Network (SATERN). Even the annual ARRL-sponsored Field Day event states, as one of its objectives, "developing skills to meet the challenges of emergency preparedness."[1]

Amateur radio's emergency preparedness and disaster-related assistance activities historically have been conducted only through terrestrial communications. That has begun to change. The Amateur Radio Satellite Corporation (AMSAT) annually conducts its own amateur radio satellite field day, held concurrently with the ARRL version. (Read results of the most recent AMSAT Field Day in this issue.) Certificates are awarded to the first place emergency power/portable station, and the "second and third place emergency operation, in addition to the first place home station running on emergency power."[2] Clearly, the emphasis of satellite field day is on using emergency power or operating portable.

Additionally, a digital microwave geosynchronous (GEO) amateur radio satellite service system is planned through a partnership between VirginiaTech, AMSAT, and Millennium Space Systems. Referred to as "Phase 4," one of the GEO satellite's intended applications is emergency communications. According to Bob McGwier, N4HY, Director of Research at the Hume Center for National Security and Technology at Virginia Tech, FEMA has stated, "If you build it, we will use it," and indicated that it would request the ARRL to use 100 units for ARES go-kits.[3]

While we clearly have no control over either the magnitude or timing of an EMP or CME event, we nevertheless can be prepared by implementing various strategies, both in space and on the ground, that can protect equipment or otherwise get systems back online and on the air as quickly as possible. Government and industry shoulder primary responsibility for protecting the electrical power grid and other vital infrastructures at the national, regional and local level. As with most indiscriminate disasters, however, the ultimate responsibility for protecting non-governmental individual spacecraft, stations, networks and systems against EMP and CME damage falls on the owner and operator – us.

In order to determine what mitigation measures might be most effective in a given scenario, we first need to understand how EMP and CME work, the different characteristics of the events we likely would face, the nature of the specific threat, and the probabilities of occurrence.

EMP

EMP and CME are quite different in how each affects the power distribution system and electronics. EMP can severely affect both electronics and the power distribution system.

Man-made Versus Natural

Much has been written about the concept of a nuclear-based EMP attack. Briefly, old Cold War enemies (i.e., China and Russia), or rogue states like North Korea and Iran, or sophisticated terrorist organizations would detonate one or more nuclear weapons high above the U.S. This would interact with the Earth's atmosphere, ionosphere, and magnetic field to produce an EMP that radiates downward on Earth, creating electrical currents and magnetic fields that could damage electrical power systems, telecommunications systems and electronic devices. The resulting effects could prove catastrophic.[4]

In his excellent QST article, "Electromagnetic Pulse and its Implications for EmComm," Bob Schroeder, N2HX, wrote that during an EMP attack, "the resulting electromagnetic field … is produced by the recoil of the electrons." As he explains, "This field propagates through space and induces a current into any metal object in its path. This can include spacecraft, aircraft or any metal conductors on, above or even below the ground."[5] (See Figure 1.) Strategically placed, a detonation producing an EMP burst could affect the entire continental U.S. (See Figure 2.)

Another kind of EMP, which could be either more or much less devastating, could be produced by a CME, as discussed below.

Dual Threat

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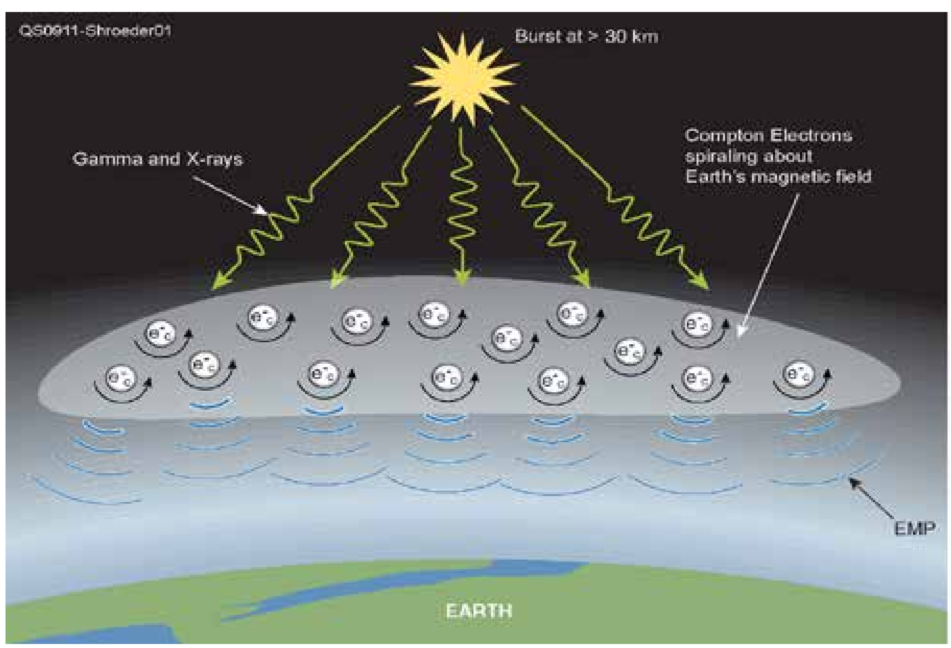

Figure 1 [courtesy of *QST*].

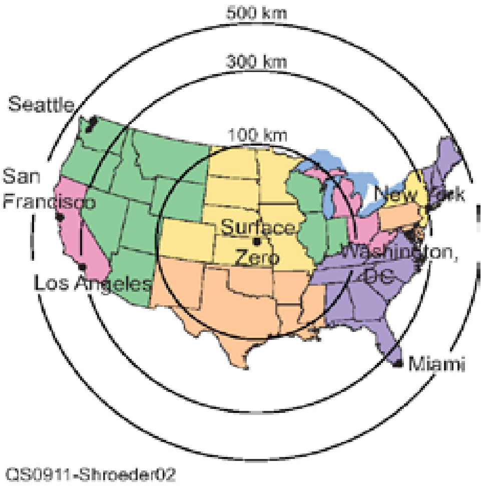

Figure 2 [courtesy of *QST*].

of the 2010 Defense Threat Reduction Agency (DTRA) report, Collateral Damage to Satellites from an EMP Attack states, "Use of a high altitude nuclear detonation as an electromagnetic pulse (EMP) attack on a terrestrial target may generate both immediate and long-term radiation threats to Earth-orbiting satellites."[6]

As we all know, the spacecraft is only half of the communications link. The DTRA's report explains that, "Ground stations are at risk from EMP effects, and the medium through which a satellite's radio signals propagate can also be disturbed for as long as several hours due to ionization of the atmosphere by the nuclear burst."[7]

1. Easy Sats, Easily Reached

According to the DTRA, low-Earth orbit (LEO) satellites "would be most affected by a high altitude EMP burst."[8] The reason is that typical altitudes for detonation of nuclear warheads creating high-altitude EMP are 40-400 kilometers. That could include a number of amateur radio satellites and the International Space Station, depending on the positions and altitudes of those spacecraft relative to the detonation.

Unlike with LEO satellites, however, the DTRA states that, "the large distance between a detonation for an EMP attack and a satellite in MEO [Medium Earth Orbit] or GEO [Geostationary Equatorial Orbit] makes the probability of damage to them very low."[9]

2. Sizzling Stations

Schroeder writes that, given the high-frequency pulse of nuclear-generated EMPs, "we can expect that conductors as short as 1/4 wavelength at, say 144 MHz, would make good EMP collectors." That would include pieces of wire, poles, antennas, rods, and pipe, among other metal objects that approximate 19 inches in length.[10]

These wires or other metal objects pick up the EMP pulse and transfer or couple it to connected or nearby susceptible devices.

Probability

While the DTRA has approximated the relative probability of damage to satellites in LEO, MEO or GEO resulting from EMP attack, no U.S. government agency appears to have stated publicly its assessment of the probability of an EMP attack. This is not surprising given the subjective, speculative and highly fluid nature of the kinds of circumstances that would result in an EMP attack.

Mitigation

When it comes to protecting LEO satellites from EMP, DTRA concluded, "radiation hardening of satellite components will likely prolong LEO satellite survival times measurably. Outstanding questions revolve around relative costs versus benefits to be derived from an investment in hardening technology."[11] In practical terms, non-profit organizations and academic institution that have begun to launch relatively simple and inexpensive LEO CubeSats (such as AMSAT and most universities) likely will find hardening technologies cost-prohibitive.

Alternative strategies include making it up in volume, which is to say that enough redundant LEO satellites spaced far enough apart could avoid a total, or perhaps even significant, loss of LEO amateur radio satellites. Another strategy simply would call for making a priority the launch of GEO and HEO satellites that could more likely continue to operate beyond the reach of a nuclear-based EMP.

When it comes to protecting ground stations, EMP mitigation is more difficult. Early tests with solid-state amateur equipment indicated very little damage as long as no long wires were attached. The key is having sufficient hardware protected from the EMP pulse so that recovery is possible.

Bob Schroeder suggests using a combination of shielding, filtering and surge protection to provide the most effective protection.[12] Surge protection can be used to short antenna cabling to ground in the event of a lightning strike. The problem is that EMP has a much faster rise time than lightning so that the kind of long wires used for lightning protection will have much too high an impedance for EMP. (See Figure 3.) Given that, Schroeder suggests, "The most effective EMP surge protectors are mounted as a part of penetrations through shielded boundaries with direct connection to the shield at the point of entry."

Schroeder also concedes that simply disconnecting sensitive equipment, though effective, may not be a viable option for

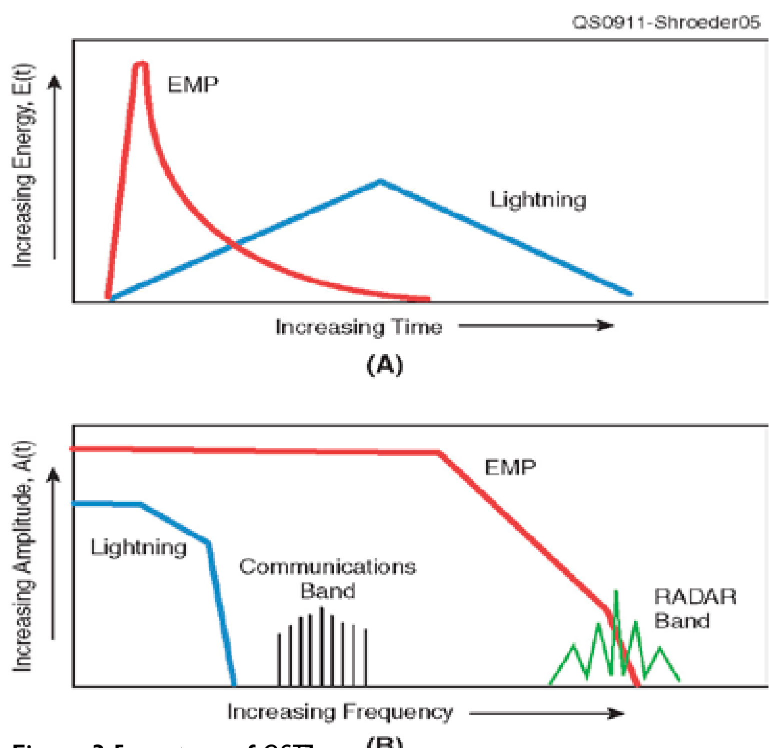

Figure 3 [courtesy of *QST*].

an operating station. This is especially true for nuclear-generated EMP because the burst likely would happen with no advance warning, unlike most thunderstorms and potentially CMEs (as discussed further below). Accordingly, maintaining backup/ redundant equipment appears to provide a more realistic option.

Carrying the idea of spare equipment further, the combination of a Faraday cage large enough to accommodate fixed station equipment, as well as a go-kit or "bug-out bag" with portable equipment, could offer some appealing benefits. Such a solution, first, would provide the flexibility of using either fixed or portable radio operation and, second, conveniently centralize backup equipment in one location along with other needed survival gear and supplies.

The Faraday cage – a large steel trash can, for example –could contain, in addition to radios, a portable power pack, such as the P3Solar Dynamo Plus used by the U.S. military, to provide a lightweight 25 W foldable solar panel that can power electronic devices including smartphones, notebook computers, and tablets. Even smaller solar chargers, like the 6.5 W EnerPlex Kickr IV, can recharge AA batteries for dual-band HTs, phones, weather and GMRS/FRS/MURS radios, GPS devices and LED flashlights like the Fenix LD12 or UltraFire. And before anyone suggests that cell phones would be useless if the power grid and cellular networks get knocked out, consider adding a set of goTennas to create your own off-grid network for text and GPS through your smartphone.

CME

CMEs are naturally occurring events in which the Sun ejects huge plumes of ionized plasma. Such plumes are many times larger than the Earth and are entwined with magnetic fields, travelling one million miles per hour or more. These fields disrupt the solar wind flow, producing disturbances that strike the Earth. Sometimes the results are disastrous.

The frequency of CMEs can vary with the sunspot cycle. During solar minimum, we may observe one CME a week, while around solar maximum the average is 2 to 3 CMEs daily.

Threat

While these frequent CMEs typically can be inconvenient or perhaps wreak havoc temporarily on telecommunications, including radio communications and portions of the power grid, they are less of a concern than the larger, more energetic variety.

In his book, *Apocalypse Unknown: The Struggle to Protect America from an Electromagnetic Pulse Catastrophe*, Dr. Peter Vincent Pry, Executive Director of the Task Force on National and Homeland Security and Director of the U.S. Nuclear Strategy Forum, writes, "If a particularly energetic one of these solar torpedoes hits the Earth, it would shudder the protective magnetosphere that surrounds our planet, and generate a powerful electromagnetic pulse (EMP) that could collapse electric power grids everywhere, plunging every modern nation into a protracted blackout. Perhaps permanently."[13]

According to NASA, the EMP blast can accelerate protons and electrons to electrify satellites and damage their electronics.

Probability

Dr. Pry suggests that a particularly large and fast CME, a solar super-storm, could be devastating:

> *The Earth is overdue for a solar super-storm that could inflict a global catastrophe. The last such super-storm, called the Carrington Event, happened in 1859. It caused fires in telegraph stations and destroyed the newly laid trans-Atlantic telegraph cable. But in those horse and buggy days civilization did not depend upon electricity. The Congressional EMP Commission estimated that a Carrington Event class geomagnetic super-storm probably occurs every century. Arithmetic suggests that, as of this writing in December 2012, as we enter another solar maximum, we may be overdue for another Carrington Event.*[14]

Pete Riley, who has studied the solar corona and inner heliosphere for about 20 years, believes that "the probability of another Carrington event … occurring within the next decade is 12%."[15] In fact, on July 23, 2012, a powerful CME flew out from the Sun at an initial speed of 2500 ± 500 km/s, fortunately directed away from Earth. However, analysis shows that if that solar storm – as large or larger than the 1859 Carrington event – had occurred in mid-July, it would have directly targeted Earth, with devastating effect.[16]

Mitigation

In preparing for a CME, one advantage we might have over a nuclear-based EMP event is some advance warning. NOAA's Space Weather Prediction Center (SWPC) and NASA monitor solar activity, issuing warnings about CMEs and other changes in the solar wind.

During the 2012 solar super-storm, one of NASA's satellites, the Solar Terrestrial Relations Observatory (STEREO-A) was in the path of the CME, and STEREO's sensors detected the CME's arrival about 19 hours after its initial detection.

With monitoring tools such as SWPC's 3-day forecast, if a massive CME were spotted, utilities might have adequate time to take protective measures, like disconnecting transformers. Satellite owners/operators potentially could decrease the likelihood of damage by switching some satellites into safe mode.[17]

Another relative advantage to the individual amateur radio satellite operator is that CMEs are low-frequency phenomena. This means that CME is unlikely to affect electronic equipment directly. Small equipment – full-duplex transceivers, HTs, PCs, power supplies, pre-amps, antennas and related equipment – are much less at risk, so long as you can unplug them in time.

Then again, in a rare super-storm, disconnecting equipment might not be completely effective. The Congressional EMP Commission discovered that the Sun produces a great geomagnetic storm every hundred years or so that can generate EMP effects – referred to a Geo-Magnetic Disturbance (GMD) – similar to a multi-megaton nuclear detonation.[18] Unlike the fast electromagnetic shockwaves of nuclear EMPs, these GMDs are relatively slow, though still powerful, and perhaps would not cause the same damage to personal equipment as nuclear-created EMPs.

A combination of whole-house and individual surge arresters that limit peak AC voltages may be the best protection against a severe CME. Disconnecting the house, or other station location, from the utility grid before an event and running on a backup generator would provide effective protection. If the surge arresters function correctly, the house wiring would not collect sufficient energy to cause any problems.

Alternatively, the station-in-a-cage solution seems like a simpler approach, either alone or in conjunction with appropriate surge protection and shielding.

Most people will have higher priorities when an EMP or major CME event happens than getting their radios working. For amateur radio operators with satellite capability, however, fulfilling the mission of emergency/auxiliary radio communications (i.e., "when all else fails"), with their special skills and experience, might be reason enough to take some relatively simple measures now to protect their ability to get back on the air when the bad day arrives.

Notes

1 Rule 2, ARRL Field Day 2016 Rules (ARRL: 2016).
2 B. Paige, "AMSAT Field Day 2016," *The AMSAT Journal*, March/April 2016, p. 22.
3 J. Kornowski, "Dateline Dayton – Notes from Hamvention 2016," *The AMSAT Journal*, May/June 2016, p. 8.
4 D. Foster, et al., "Volume 1: Executive Report," *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack*, 2004, p. 1 [Commission Report].
5 H. R. Schroeder, "Electromagnetic Pulse and Its Implications for EmComm," *QST*, Nov. 2009, p. 38 [Schroeder].
6 E. Conrad, et al., *Collateral Damage to Satellites from an EMP Attack* (Defense Threat Reduction Agency: 2010), p. 1 [DTRA Report].
7 DTRA Report, p. 1.
8 DTRA Report, p. 5.
9 Commission Report, p. 111.
10 Schroeder, p. 39.
11 DTRA Report, p. 134.
12 Schroeder, p. 40.
13 P. Pry, *Apocalypse Unknown: The Struggle to Protect America from an Electromagnetic Pulse Catastrophe* (2013) p. 3 [Pry].
14 Pry, p. 3.
15 P. Riley, "On the Probability of Occurrence of Extreme Space Weather Events," *Space Weather, Vol. 10* (American Geophysical Union: 2012), p.1 [Riley].
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17 J. Stromberg, "What Damage Could be Caused by a Massive Solar Storm?," *Smithsonion.com*, 2013.
18 Pry, p. 15.

Aboard the Queen Mary – W6RO on AO-7

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On March 4, 2016, I was in southern California to give a presentation and demonstration of satellite operating for the Associated Radio Amateurs of Long Beach (ARALB). The Queen Mary's amateur radio station, W6RO, is operated by ARALB, and the club had invited me to visit the ship's wireless station. So, the next day, while sightseeing with Endaf Buckley, KG6FIY, around Los Angeles, we headed to the Queen Mary in Long Beach harbor.

W6RO has several operating positions, covering bands from HF through 70 cm. One of the stations is set up for satellite operating, with a Yaesu FT-847, Yaesu az/el antenna rotator, and long-boom Yagis for 2 m and 70 cm (Figure 1). The W6RO satellite station was originally set up in the days of AO-13, and has not been used much in recent years. While looking around the station, W6RO's station manager, David Akins, N6HHR, asked if I wanted to try operating the satellite station. I discovered

Figure 1 — W6RO satellite antenna [Patrick Stoddard, WD9EWK, all photos].

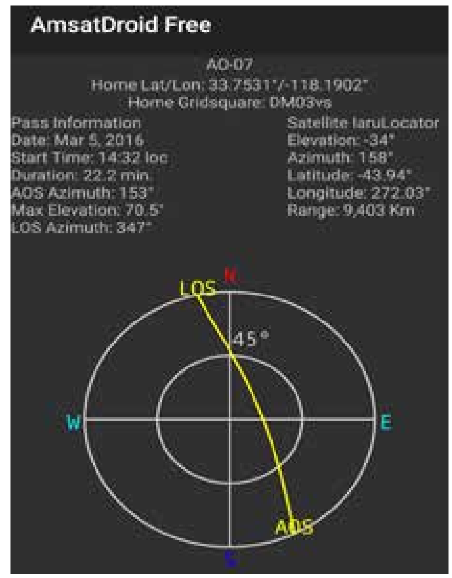

Figure 2 — AO-7 pass prediction.

Figure 3 — W6RO station manager, David Akins, N6HHR.