The

**Broadcasters' Desktop Resource**

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# The Maintenance Shift

## EMP Dangers in the Broadcast Plant

### By Glen Clark

*[October 2017] This is Part 3 of Glen Clark's look at EMPs (Electromagnetic Pulses): what they are, what dangers they present to broadcasters, and how to minimize damage from an EMP.*

The broadcast owner or engineer cannot prevent an EMP. But with understanding about the nature of EMPs and proper planning, service can be restored as rapidly as possible.

We left off last time discussing the three specific physics phenomena which can bring society to its knees – not one of them rocket science – and just what broadcasters can – and cannot – do to prepare for possible implementation.

The three Electromagnetic-Pulse-Induced Failure Modes we want to discuss are:

1) insulation punch-through from overvoltage which causes carbon tracking,

2) catastrophic failure of the crystal lattice in the semiconductor substrate in a transistor, CPU, ASIC, IC or other circuit component, and

3) fusible-link style failures in an internal bond wire in an IC or in a circuit trace on a circuit board.

### FAILURE MODE #1: INSULATION PUNCH-THROUGH

All chemical elements and compounds have electrons which inhabit the outer surface of the molecule.

If those electrons can easily be traded to an adjacent molecule, as with silver, copper and aluminum, the element is a conductor.

If the electrons are very tightly held, current does not flow from one molecule to the next molecule easily and the material is an insulator.

However, if you apply enough voltage to an insulator, even the tightly-held electrons can be ripped off. This "flash-over" is an instantaneous event caused by a Voltage spike.

The result is a change in chemical composition takes place.

The materials that result often include carbon compounds, which are often reasonable conductors. The result is that the insulation just became a conductor and it will never revert to its previous characteristics.

## THE CARBON TRACK

Sometimes, the newly-created conductive path, called a "carbon track," is enough to make the equipment stop working instantly.

Voltage through the carbon track creates heat. In a darkened room, one may observe an orange glow like that of the tip of a cigarette. And this heat may convert additional insulating material into a carbon track.

But, even if it does not, failure of the device may not be far away. Though the Voltage spike has passed, if the device continues to operate, the normal operating Voltage is still applied. The lower, non-spike Voltage is, as before, insufficient to reformulate the chemical composition of the insulation. However, some of what was insulation between the two potentials is now a conductor. And a different chemical breakdown takes place.

Carbon tracking can be a progressive failure, also called a "cascade failure," which gets worse with time. More damaged insulation will cause more current to flow. More current causes more heat, which causes more damaged insulation. It is not uncommon for a device to fail three minutes or even three days from the initial flashover.

## POTENTIAL FAULT LOCATIONS

Base insulators and guy wire insulators are obvious potential fault locations for AM stations.

But FM stations are not off of the hook. And, diesel generators, which will be covered in more detail in their own section, are essential for both AM and FM facilities in the event of an extended outage of the main commercial electrical feeds.

Coax can flashover along the spacers that separate the inner and outer conductors. From that point, RF will keep the progressive decomposition of the insulation alive.

## PLAN AHEAD

Do you have a spare run of coax already on-site, on a 10-foot-diameter wooden spool with shorts and caps on both ends?

Why is this important? Have you ever been on either the Gulf Coast or the Atlantic Coast when a hurricane was inbound? If so, did you see any bottled water or flashlight batteries on the shelves?

As so many find out each time there is a hurricane, the time to acquire emergency supplies is before the storm is 20 minutes away.

The same logic applies here. The time to order a 500-foot roll of 3-inch Heliax is before the EMP, not after the EMP. Just think: if 700 stations are off the air due to failed coax, is there a reason to believe that your order will be the first one serviced?

Even if you are in the top 100 of the orders to be filled, what does that convert to in number of weeks off the air? The lead time for an order of coax that you would be quoted today is not the same as the lead time that would be available after a large surge in orders.

Coax vendors do carry some inventory to allow them to ship from stock for the random station that suffered storm damage. But they do not have deep stock, sufficient inventory that would allow them to quickly fill dozens of orders at once.

And that presumes that the coax vendors do not have their own problems with plant, family and personal vehicles.

## IS FEMA THE ANSWER?

It is reasonable to presume that, if the coax vendors are not able to quickly return to high-volume production on their own, FEMA would devote significant resources to reanimating the coax vendors' means of production.

Why? Because FEMA will not have any choice but to get involved.

Perhaps you are not a single FM antenna on a single tower on a mountain. Or, perhaps you are on the Senior Road Tower. If the Senior Road combiner had an EMP-induced flashover and subsequent meltdown, how long would it take Dielectric to put a replacement unit on the site?

Put another way, if your antenna is fed through a 13-way ERI combiner, how long would it take the manufacturer to put a complete new system on your loading dock?

Of the three failure modes, insulation punch-through and subsequent carbon track progresssive failure is likely to be the mode that causes the largest disruption after an EMP and is also the most difficult to repair. This is the biggie.

## FAILURE MODE #2: "MICROSCOPIC PUDDLES OF MOLTEN SILICON"

Any solid-state device is a stack of layers, etched in a carefully-grown crystal of semiconductor material.

Germanium, silicon, certain metal oxides and Gallium Nitride are the most common substrate materials. All of these materials are, to a greater or lesser degree, electrically fragile and physically fragile. Gallium Nitride is the most robust material in that list

The layers alternate between insulators and sometimes-conductors. The process used to build the layers in the substrate is known as lithography. To accomplish miniaturization, the layers are quite thin.

## SHATTERING OR MELTING THE CRYSTAL LATTICE

It does not take a lot of energy to destroy one of these thin layers. Static electricity is enough. That is why ICs, PGAs, ASICs, CPUs and other high-density devices are shipped and stored in plastic tubes which protect the semiconductor from static.

When the core of a transformer experiences an insulation failure, that is primarily a chemical change. But if a voltage spike is applied to a semiconductor, a physical change is more likely. That is, the crystal lattice shatters or melts at a microscopic level.

The carefully etched, precision structure of the silicon is replaced with microscopic puddles of molten silicon. The puddles quickly cool and become solid again. But not before several adjacent layers have melted together, ending the proper function of the chip.

## FAILURE MODE #3: BLOWING THE BOND WIRES

Fuses come in all different shapes and sizes.

The entry of the AC power mains from the outdoor "snorkel" to an indoor fuse box may have a cartridge style fuse which is roughly the size of a ballpark hot dog. Before circuit breakers, individual circuits were often protected by a screw-in fuse that had the same base as an incandescent bulb. Even today, rack-mounted broadcast equipment is often protected with a "3AG" fuse.

None of these three fuses look alike. But they all function the same. A thin wire with a predictable melting temperature is placed in series with the load. If the current is below a particular value, the wire functions just as a copper wire would. But, if the current exceeds the rated current, the wire will melt, opening the circuit.

Hence, the internal structure of an integrated circuit, without intending to, provides the identical function. Common 14-pin DIP ICs have a similar structure, even though their purposes are different. A 7401 TTL chip, a CD4001 CMOS gate, a TL074 analog op-amp, and a quad matched transistor have the same physical profile. In fact, if you remove the markings with xylene, it is hard to tell which is which.

If you were to carefully remove the top half of the black, plastic DIP package, those 4 chips are still quite similar in appearance inside. The silicon chip inside is roughly 1/4 inch by 1/4 inch. The chips have 14 pads on them for connection. Fourteen thin bond wires connect the chip pads to the 14 pins that extend through the DIP package to the outside world. These 14 bond wires are thinner than a human hair.

And, while no fuse action was desired or intended, the small dimension of the bond wires provides fuse action.

## FAIL-OPEN MODE VS FAIL-SHORTED

When a device has been damaged by an EM pulse, the ball can bounce in several different directions.

A blown bond wire will "fail open." The pin on the IC package is no longer connected to the internal part that it should be connected to. It is identical to having a blown fuse in the circuit,

On the other hand, a shattered silicon chip will usually fail-shorted, as will a carbon-tracked insulator also usually fail-shorted.

## SELF-HEALING VERSUS NON-HEALING FAILURE MODES

Some physical systems will self-heal when an overload is removed.

For example, a road bridge that has deformed because too many heavy trucks are stopped on the bridge may spring back to its original shape if the excess weight is removed.

In contrast, none of the EMP failure modes are the kind that self-heal. If a bond wire has blown or if the silicon substrate has shattered, human intervention is required to restore proper operation. And that intervention is to solder in a replacement IC or to replace the circuit boards that the IC is part of.

Furthermore, if an insulator has carbon-tracked, that will not get better on its own either.

## NECESSARY SPACING

For more than a century, it has been standard practice to place substation transformers with nothing between them other than air.

The people who made these decisions are not here to question, but this practice has always made "secondary detonations" possible. A fault and explosion in one transformer could throw shrapnel which could cause adjacent transformers to fail also, compounding the problem.

**Courtesy of Grove City, PA Borough Electric**

The photo above shows a new policy used for many utilities.

There are two similar, large transformers at this substation. One is in the foreground. You can observe the six bushings (insulators) for the twin transformer, just poking above the concrete block wall. The block wall is designed to prevent an explosion from one transformer from destroying its twin with high kinetic energy.

Note also the dirty gray color of the concrete oil sump beneath the transformer. Notice that the block wall is much whiter and newer. The block dividing wall was added last year to a much older substation.

Retrofitting protection features, such as the masonry subdivider, to existing substations to increase reliability is becoming more common.

## EMP SPEED CONSIDERATIONS

Spark gaps or gas tubes have benefits that mechanical circuit breakers lack in an EMP event.

That is because an EMP is often too fast for mechanical circuit breakers to respond

Spark gaps have no moving parts and therefore no inertia of rest. This means that the spark gap can begin working before a mechanical circuit breaker can begin working.

While the difference in response time will be only a small fraction of a second, it can make the difference between saving the equipment and not saving the equipment.

## PHILOSOPHER OF RELIABILITY ENGINEERING

I was the VP of Engineering in the early 90s for an Atlanta-based broadcast transmitter manufacturer.

We actually were building a quite reliable tube-type transmitter. But some of our competitors were already shipping transmitters that were solid-state throughout.

While we looked good in a thorough comparison, we were losing the public relations battle. Our competitors were yelling loud and often that solid-state was better.

We tried to close the gap by replacing the relay and toggle switch control ladder with a single-board computer with LCD display. Even if our PA was not transistorized, we still had a very sophisticated and informative control system.

## FOE OF RELIABILITY

Unfortunately, our changes proved to be a step backward.

Originally, the transmitter had a Mean Time Between Failure (MTBF) of 10,000 hours. However, the computer that ran the front panel turned out to have had an MTBF of 2,000 hours.

At best, the net-net reliability of a system will never be more than the reliability of the least reliable component. So, basically, we had just converted a transmitter with a 10,000 MTBF into a transmitter with a 1,999 hour MTBF.

In the end, the transmitter we built with the front panel that looked like a video game was 1/5th as reliable as the clunky-looking transmitter with those old style toggle switches and the analog meters!

The moral is, you have to let go of your preconditioning.

## HOW ENGINEERS PLAN AHEAD

At this point in our discussion, we need to step back and consider our entire system as a whole.

As we go, we want to analyze each component of your system and identify its own issues, vulnerabilities, and considerations.

So, in our next part, we start with power in and seek how to make sure the end result is power out.

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