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Microwave Memos
Memo 4

Preliminary Near-Term Criterion for Single - Pulse HPM

I. Introduction

With the development of appropriate HPM sources and antenna designs, it is perhaps time to start thinking about what some first generation HPM weapons might produce. This in turn can be used to formulate a criterion for system survival in such environments.

As discussed in [2] the frequency range of interest centers around a GHz, say a few hundred MHz up to several GHz. This is based on interaction with typical systems through unintentional signal paths (back door coupling). The 1 GHz number comes from typical small dimensions in construction (small windows, rivet spacing, spacing of cables from ground planes, etc.). Outside this generic frequency band there can be important frequencies with intentional interaction paths (front door coupling). This depends on specific system considerations and whether the designers have hardened such obvious interaction paths.

This criterion is based partly on experimental source data, and partly on reasonable engineering extrapolations concerning sources and antennas. As such one should assign an accuracy of a factor of a few (up or down) to what can be realized in the near term. Note that what <u>can</u> be realized is not necessarily what <u>will</u> be realized in the near term.

Note that here we are addressing single pulse operation of the HPM weapon, with the purpose of damaging or functionally upsetting the system so as to deny mission accomplishment, not necessarily destroy the system. Repetitive pulsing in the sense of a high-power jammer is another subject. Multiple pulsing of course depends on the possible weapon (primarily source and power supply) design, and is not addressed here.

II. Sources

There is a large literature on HPM sources, primarily in the IEEE Transactions on Plasma Science, as well as a book [8]. This will not be reviewed here, the reader having access to all this if desired.

Note first that the frequency range of interest (intentionally a little vague at the extremities) is

$$\text{a few 100 MHz} < f < \text{several GHz} \tag{2.1}$$

Next consider power. First define a concept of <u>useful</u> power. This is the power transported away from the source in the lowest order made of one or more standard rectangular H-mode waveguides [3]. Note that for multiple waveguides the relative phases must be controlled in the present definition. There may be some slight improvements made in the power handling capabilities of such guides by modification of the cross-section shape. However, a rectangular guide operated in the lowest order mode (say with frequency a little below that of the cutoff frequency of the second mode) should be adequate, say, for example, under high-vacuum conditions. Note that under this definition not all HPM sources may be useful for HPM weapons as considered here. Furthermore, the frequency range will slant the view to certain types of sources.

Note that magnetrons and vircators have already produced useful power in this frequency range [8]. Other promising sources (such as relativistic electron-beam klystron-like devices) need to have their outputs similarly configured. For a near term power level one might take 10 GW at 1GHz. Then we need to have the power decrease as frequency increases. Some like scaling the source power P_s proportional to λ^2 based on physical considerations related to the dimensions of the Xatron (generalized microwave source). A more reasonable current technology might have P_s scale more like λ. This would give 1 GW at 10 GHz and 100 GW at 100 MHz. Note that EMP simulators rising in like 5ns or so currently give several 100 GW (or tenths of a TW).

So let us propose in the range of (2.1)

$$P_s \approx \frac{10^{19}}{f} \approx \frac{1}{3} \times 10^{11} \lambda \quad \text{Watts} \tag{2.2}$$

with λ in meters (standard mks units). Note that power is an average over one cycle. Here only a single source is assumed and a later criterion might assume an array of 10 or so phase locked sources.

Concerning the pulse width T, let us take

$$T = 100 \text{ cycles} = \frac{100}{f} = 100 \frac{\lambda}{c} \tag{2.3}$$

At 1 GHz this is about 100ns, a reasonable figure. Note that from an interaction viewpoint 100 cycles should be enough to ring up most system resonances and thereby realize the maximum peak voltage (or current) at the failure ports of interest. There will of course be some cases where the "Q" of the system resonance is high enough that (2.3) could be usefully made longer (for obtaining peak signal). In an energy sense, of course, larger T will increase the energy delivered (from the incident field) to the failure port.

Combining (2.2) and (2.3) gives the radiated energy as

$$U_s = P_s T \approx 10^{21} f^{-2} \approx 10^4 \lambda^2 \quad \text{Joules} \tag{2.4}$$

which is about 1 kJ at 1 GHz. Note that this is for a rectangular modulated pulse, 100 cycles wide, Other pulse shapes change this result, but not significantly for present purposes.

III. Antennas

Having the source producing useful power, this can be routed using standard microwave techniques into high-gain antennas to efficiently illuminate the target. Remember that it is the strength of the signal illuminating the target, not that produced by the source, which is the relevant weapon parameter. Dipole patterns, or other patterns which spread out the energy (such as those with conically shaped beams with nulls in the center (cones of protection for the target)) are not interesting. Antenna technology for this frequency band and high powers of interest indicate that paraboloidal reflector antennas (perhaps with offset Cassegrain feeds for beam steering) are most appropriate [1, 4, 6].

Summarizing from [2] we have for an appropriately focused antenna

$$E = E_o \frac{A}{\lambda r}$$

r ≡ distance to target

A ≡ aperture area

E_o ≡ electric field magnitude aperture (assumed (3.1)

uniformly illuminated)

E = electric field magnitude incident on target

Note that E_o should be limited to roughly 1MV/m for air breakdown limitations near the earth surface.

The power radiated by the antenna is (averaged over one cycle)

$$P = \frac{E_o^2}{2Z_o}A = \eta P_s \tag{3.2}$$

$\eta \equiv$ efficiency of antenna system (for present estimated as 1)

$Z_o \approx 377\Omega$ (wave impedance)

Then we have

$$E = \frac{[2Z_oP_sA]^{\frac{1}{2}}}{\lambda r} \approx \frac{5\times10^6}{r}\left(\frac{A}{\lambda}\right)^{\frac{1}{2}} \frac{V}{m} \tag{3.3}$$

In power density units we have

$$p = \frac{1}{2}\frac{E^2}{Z_o} = \frac{P_sA}{[\lambda r]^2} \approx \frac{1}{3}\times10^{11}\frac{A}{\lambda r^2} \frac{W}{m^2} \tag{3.4}$$

The aperture area A is a weapon design parameter to be chosen. The examples in [4] are for $20m^2$, $40m^2$, and $100m^2$. The area needs to be as large as practical since it so directly influences the fields on target. The smaller of these numbers might be appropriate for a mobile (truck mounted) weapon. The $100m^2$ size, if to be mobile, might be more appropriately mounted on a ship. If mounted on an aircraft we might expect much smaller areas, and hence fields on target, available.

IV. Concluding Remarks

In applying this criterion note that the distance r to the target must be chosen. This is very scenario dependent. With a pulse width of 100 cycles we still express E (or p) as a function of P_s (from (2.2)), E_o ($\approx$ 1MV/m maximum allowed field on aperture), A, and r. Consider the algorithm:

a. For selected f (target sensitive) find P_s from (2.2).

b. For selected A find E_o from (3.2). If this exceeds $\sim$ 1MV/m reduce P_s to P in (3.2) with $E_o \approx 1MV/m$.

c. For selected r find E from (3.1) using E_o from above, or from (3.3) using P_s (possibly corrected to P) as above. If this E exceeds $\approx 1MV/m$ (noting that sufficiently close to the antenna focusing allows E to exceed E_o) then limit E to this value (or at most a few MV/m).

Note that in spaceborne applications these fields can be exceeded since the limitation of air breakdown is replaced by other processes such as field emission.

For a more far - term criterion one might increase P_s by a fator of 10 [7]. This may involve arrays of phase controlled sources [5].