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Viruses Illuminated by Radio Frequencies: A Review of Openly Published Literature

by Gregory J Mazzaro and Kyle A Gallagher

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14. ABSTRACT
The authors propose that it is possible to neutralize COVID-19 using RF energy transmitted remotely, such as from a radar. To begin investigating this possibility, the authors conducted a review of openly published literature pertaining to viruses illuminated and destroyed by microwaves and other RF sources. This memorandum report summarizes that body of literature.

15. SUBJECT TERMS
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1. Introduction

The authors have proposed that it is possible to neutralize coronavirus disease 2019 (COVID-19) using radio frequency (RF) energy transmitted remotely, such as from a radar. To begin investigating this possibility, the authors conducted a review of openly published literature pertaining to viruses illuminated (and often destroyed) by RF. This memorandum report summarizes that body of literature.

2. Literature Review

The literature relevant to neutralizing viruses follows this general progression:

- consider illumination by acoustic waves,
- study vibrations in virus particles by modeling them as spheres,
- observe real virus samples illuminated by acoustics,
- consider illumination by microwaves (RF radiation),
- measure the destruction of real virus samples heated by microwaves,
- observe the conversion of energy between microwave-RF and acoustic vibrations,
- measure the destruction of viruses caused by microwave-acoustic coupling, and
- develop an apparatus for destroying aerosolized viruses, focusing on frequencies *above* conventional microwave-oven frequencies.

Open literature assumes that viruses harmful to humans generally have a spherical shape. (The next most popular model for a virus's shape is a cylindrical rod.) Absorption of acoustic energy by spherical particles is very frequency dependent. The seminal paper used to understand the behavior of vibrating spherical particles was published in the late 1800s.[1] Using the classic ("elastic sphere") model and a slightly more sophisticated one (the "liquid drop"), estimates of acoustic-resonant frequencies for a dozen different materials were calculated.[2] Estimates of such frequencies specifically for *viruses*—assuming that their elastic properties closely match those of a lysozyme protein crystal (a commonly used mechanical model for virus particles)—were calculated shortly thereafter.[3]

After mathematically deriving how a spherical particle embedded in a uniform surrounding medium deforms when acoustic energy is applied, Talati and Jha[4] comment that a spherical virus particle's "breathing mode" (radially inward-and-

outward vibration) could be excited to ultimately destroy a sample of that virus. Meanwhile, experiments performed on the Satellite Tobacco Mosaic Virus indicated that real viruses do *not* behave according to the lysozyme-protein assumption[5] because the speed of sound in a real virus is very different from the speed of sound in a lysozyme crystal.

Along a different line of discovery, researchers found that airborne *bacteria* may be destroyed by bombarding them with RF energy at commercial-microwave frequencies (i.e., 2.45 GHz). One team of scientists destroyed samples of Bacillus Subtilis and Pseudomonas Fluorescens by piping the aerosolized bacteria through a commercial microwave oven via holes drilled into its sides with tubes running in and out.[6] This same group modified its experimental apparatus and successfully destroyed bioaerosols including fungi[7] and the MS2 Bacteriophage virus.[8] A similar experiment demonstrated the destruction of an aerosolized version of E coli.[9]

Another research group destroyed E coli by placing stationary samples (suspended in a broth) inside of a (traditional rotating-plate) microwave for up to 30 s.[10] Yet another group destroyed Hepatitis C and Human Immunodeficiency Virus-1 in the same manner.[11] Measurements taken while destroying E coli[12] and Lactobacillus Casei[13] indicated that these viruses are destroyed (at 2.45 GHz) primarily by heat; in other words, just as many viruses may be destroyed by heating them with a conventional oven rather than using a kitchen microwave. Also, the apparatus for destroying aerosolized viruses is far more efficient than the apparatus used to destroy viruses suspended in water or another form of broth, because a large portion of the microwave energy incident on the suspended virus is lost to heating the water/broth instead of the virus itself.[14]

By applying RF radiation, in addition to heating, it is also possible to induce acoustic vibrations in a virus. This microwave-to-acoustic energy conversion is known as microwave resonant absorption (MRA).[15,16] To achieve this effect, theory predicts that frequencies significantly higher than those available from conventional kitchen microwaves must be used.[17] Measurements of MRA were performed on the H3N2 virus (a form of Influenza type A), using frequencies between 6 and 12 GHz, and the power threshold at which the virus was destroyed was catalogued.[18] The experimenters illuminated the virus samples by placing them directly in front of horn antennas (i.e., in the near-field). The frequency that most effectively destroyed Influenza A, a "spherical" virus, was 8.4 GHz. Destruction by MRA was also observed for a "rod-shaped" virus: White Spot Syndrome.[19]

Towards developing a portable virus-sanitizing apparatus, a reflectarray (horn antenna + reflective surface used to focus microwaves to a point) was designed,

which successfully destroyed the H3N2 virus.[20] Frequencies between 6 and 18 GHz were used to illuminate the samples; the frequency that most effectively destroyed the virus was 8 GHz.

Researchers at the Air Force Research Laboratory simulated, constructed, and tested a set of wave guides through which they intend to pipe aerosolized coronavirus; they will illuminate samples at frequencies between 2.8 and 7.5 GHz.[21] Initial measurements will use a human-safe surrogate, Bovine coronavirus, in place of COVID-19.[22]

3. Conclusion

Using this literature review as a starting point, the authors intend to begin laboratory experiments to study the effectiveness of neutralizing viruses remotely using radiation sources similar to those implemented for ground-penetrating radar. Initial tests will use frequencies near 8 GHz to illuminate inert virus samples and dielectric surrogates, which are electromagnetically similar to COVID-19.

4. References

1. Lamb H. On the vibrations of a spherical shell. Proc London Math Soc. 1882 Nov;1–14(1):50–56.
2. Ford LH. Estimate of the vibrational frequencies of spherical virus particles. Phys Rev E. 2003 May;67(5):051924(1–6).
3. Talati M, Jha PK. Acoustic phonon quantization and low-frequency Raman spectra of spherical viruses. Phys Rev E. 2006 Jan;73(1):011901(1–6).
4. Galstyan V, Pak OS, Stone HA. A note on the breathing mode of an elastic sphere in Newtonian and complex fluids. Phys Fluids. 2015 Mar;27(3):032001(1–13).
5. Stephanidis B, Adichtchev S, Gouet P, McPhearson A, Mermet A. Elastic properties of viruses. Biophys J. 2007 Aug;93(4):1354–1359.
6. Wu Y, Yao M. Inactivation of bacteria and fungus aerosols using microwave irradiation. J Aerosol Sci. 2010 July;41(7):682–693.
7. Wu Y, Yao M. Effects of microwave irradiation on concentration, diversity and gene mutation of culturable airborne microorganisms of inhalable sizes in different environments. J Aerosol Sci. 2011 Nov;42(11):800–810.
8. Wu Y, Yao M. In situ airborne virus inactivation by microwave irradiation. Chinese Sci Bull. 2014 Mar;59(13):1438–1445.
9. Woo MH, Grippin A, Wu C-Y, Wander J. Microwave-irradiation-assisted HVAC filtration for inactivation of viral aerosols. Aerosol Air Qual Res. 2012 June;12(3):295–303.
10. Wang A, Cheng N, Liuo Y-T, Lin K. Inactivation of bacteriophage by microwave irradiation. J Exper Microbiol Immunol. 2001 Dec;1:9–18.
11. Siddharta A, Pfaender S, Malassa A, Doerrbecker J, Anggakusuma, Engelmann M, Nugraha B, Steinmann J, Todt D, Vondran FWR, Mateu-Gelabert P, Goffinet C, Steinmann E. Inactivation of HCV and HIV by microwave: a novel approach for prevention of virus transmission among people who inject drugs. Sci Rep. 2016 Nov;6:36619(1–10).
12. Fujikawa H, Ushioda H, Kudo Y. Kinetics of escherchia coli destruction by microwave irradiation. Appl Environ Microbiol. 1992 Mar;58:(3):920–924.

13. Kakita Y, Kashige N, Murata K, Kuroiwa A, Funatsu M, Watanabe K. Inactivation of lactobacillus bacteriophage PL-1 by microwave irradiation. Microbiol Immunol. 1995 May;39(8):571–576.

14. Wang C, Hu X, Zhang Z. Airborne disinfection using microwave-based technology: energy efficient and distinct inactivation mechanism compared with waterborne disinfection. J Aerosol Sci. 2019 Nov;137:105437(1–8).

15. Liu T-M, Chen H-P, Wang L-T, Wang J-R, Luo T-N, Chen Y-J, Liu S-I, Sun C-K. Microwave resonant absorption of viruses through dipolar coupling with confined acoustic vibrations. Appl Phys Lett. 2009 Jan;94(4):043902 (1–3).

16. Liu T-M, Chen H-P, Yeh S-C, Wu C-Y, Wang C-H, Luo T-N, Chen Y-J, Liu S-I, Sun C-K. Effects of hydration levels on the bandwidth of microwave resonant absorption induced by confined acoustic vibrations. Appl Phys Lett. 2009 Oct;95(17):173702(1–3).

17. Uzunoglu NK. Theoretical analysis of the induction of forced resonance mechanical oscillations to virus particles by microwave irradiation prospects as an anti-virus modality. Preprints (life sciences, virology). 2020 Apr.

18. Yang S-C, Lin H-C, Liu T-M, Lu J-T, Hung W-T, Huang Y-R, Tsai Y-C, Kao C-L, Chen S-Y, Sun C-K. Efficient structure resonance energy transfer from microwaves to confined acoustic vibrations in viruses. Sci Rep. 2015 Dec;5:8030(1–10).

19. Sun C-K, Tsai Y-C, Chen Y-J E, Liu T-M, Chen H-Y, Wang H-C, Lo C-F. Resonant dipolar coupling of microwaves with confined acoustic vibrations in a rod-shaped virus. Sci Rep. 2017 July;7:4611(1–9).

20. Hung W-T, Tung J-J, Chen S-Y. A focusing reflectarray and its application in microwave virus sanitizer. Radio Sci. 2014 Oct;49(10):890–898.

21. Hoff BW, McConaha JW, Cohick ZW, Franzi MA, Enderich DA, Revelli D, Cox J, Irshad H, Pohle HH, Schmitt-Sody A, et al. Apparatus for controlled microwave exposure of aerosolized pathogens. Rev Sci Instrum. 2021 Jan;92(1):014707(1–10).

22. Hoff BW, McConaha JW, Cohick ZW, Franzi MA, Enderich DA, Revelli D, Cox J, Irshad H, Pohle HH, Schmitt-Sody A, et al. Microwaves used to deactivate coronavirus, flu, other aerosolized viruses. Review of Scientific Instruments; 2021 Jan 26 [accessed 2022 Nov 23]. https://publishing.aip.org/publications/latest-content/microwaves-used-to-deactivate-coronavirus-flu-other-aerosolized-viruses.

List of Symbols, Abbreviations, and Acronyms

ARL	Army Research Laboratory
COVID-19	coronavirus disease 2019
DEVCOM	US Army Combat Capabilities Development Command
MRA	microwave resonant absorption
RF	radio frequency

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