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Improvements in Techniques of Microwave Thermography

Annual Summary Report

15 November 1984 - 30 June 1985

Alan H. Barrett

October 1987

Supported by

U. S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, Maryland 21701-5012

Contract No. DAMD 17-83-C-3025

Research Laboratory of Electronics
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, Massachusetts 02139

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Research Laboratory of Electronics Massachusetts Institute of Technology 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 77 Massachusetts Avenue Cambridge, MA 02139	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION US Army Medical Research and Development Command 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAMD 17-83-C-3025
8c. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, Maryland 21701-5012	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61102A PROJECT NO. 3M1-61102BS10 TASK NO. CE WORK UNIT ACCESSION NO. 114

11. TITLE (Include Security Classification)
Improvements in Techniques of Microwave Thermography

12. PERSONAL AUTHOR(S) Alan H. Barrett

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Annual Summary	FROM 11/15/84 TO 6/30/85	October 1987	12

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
06	03		Microwave Thermography
06	13		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Mrs. Virginia M. Miller	22b. TELEPHONE (Include Area Code) 301/663-7325 22c. OFFICE SYMBOL SGRD-RMI-S

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFED

SUMMARY

During the period 15 November 1984 to 30 June 1985 our efforts continued to make bistatic observations whereby the scattered radiation from an embedded object is studied as a function of the size of the scattering object relative to the wavelength of the radiation to assess the proper wavelength for hyperthermia treatment of malignant tumors. This work terminated in March 1985 as Ms. Ruth Rotman, the only graduate student on the project, began concentrated preparation of her M.S. thesis.

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BODY OF THE REPORT

During the period 15 November 1984 to 30 June 1985 our research and development concentrated on bistatic measurements whereby a scattering object is illuminated by a source of incoherent microwave noise power and the reflected power is detected by a radiometer. The result of this research is summaried below.

A radiometer-based system which measures temperature, emissivity, and bistatic backscatter was used to study possible resonances in the backscatter as a means of sensing the size of the backscatter and the degree to which such resonances can be exploited to maximize the heat generated within the scatterer.

Passive microwave thermography for breast cancer detection uses a radiometer to measure the thermal patterns of the breast. Thermal radiation from the body couples into the system through an antenna. With reflection-compensating radiometer, the emissivity at the antenna-human tissue interface can be measured. A change in the dielectric properties of what lies beneath the skin can change the measured reflection coefficient at the antenna. Abnormal thermal patterns and possibly anomalous dielectric constants may indicate the presence of disease. Additionally, bistatic scattering measurements can be made with components of the same system. In previous clinical tests, only temperature has been regarded as a diagnostic criterion. Measuring all three types of data - emissivity, temperature and scattering - should provide additional information about tumor size and composition, and the appropriate frequency for hyperthermia.

Breast tumors are superb candidates for microwave imaging since they are high-water content tissues in a low-water content environment. Measurements have shown that the ratio of the real part of the dielectric constants of a tumor to breast tissue is about 8 to 1 and the ratio of their conductivities is 10 to 1. A lossy dielectric body will both scatter and absorb energy when irradiated. The amount of the resulting backscatter depends on the relative dielectric constants and the ratio of the size of the body to the wavelength in the surrounding medium, λ_m. For a dielectric sphere, the backscattering cross-section varies as the fourth power of its radius, an when a/λ_m is less than 0.1, the Rayleigh region. When a/λ_m is greater than 1, the scattering cross-section curves undergo a series of resonances before approaching the values predicted by geometrical optics, the Mie region. A non-spherical object exhibits similar behaviour. Therefore, multi-frequency readings of reflection and scattering around the neighborhood of the resonance of a tumor might indicate its presence and physical properties. Our reflection-compensating radiometer, working in an unbalanced mode, permits the computation of the reflection at the antenna-body interface. However, the greater portion of the reflection comes from the skin, not from underlying tissues. To avoid this problem, we are developing a second technique - bistatic scattering. There are two methods of implementation. In the first, a broadband method, we transmit noise from a 90,000°C noise tube through one open-ended waveguide and receive the resulting reflection with a second E-plane coupled identical antenna. Our radiometer converts the reflection into an equivalent temperature. A second method transmits power from a signal generator at a specific frequency and uses a network analyzer to measure both magnitude and phase of the returned signal. The initial direct coupling between the two antennas can be compensated in the analysis through vector subtraction. Since the scatter comes principally from the common volume where the two antennas couple together, the effect of the skin will be minimized. The injected signal need be only a fraction of a milliwatt - too low to present any health hazard.

As in thermography, corresponding readings on the right and left breasts can be compared to exploit their symmetry for reflection and scattering mearurements. Although other biological structures in the breast scatter, the slope of the backscatter versus frequency curves should substantially differ for the two breasts as the tumor's cross-section passes from the Rayleigh to the Mie region. Moreover, by determining the location of the first resonance and the slope of the curve near this frequency, we may learn more about the size and dielectric constant of the object than from radiometric results. During the treatment of the tumor, the resonance could be monitored. An increase in the resonant frequency may be indicative of regression. Also, the slope of the curve might relate to the water content of the tumor.

An advantage of scattering methods is sensitivity. The minimum size of an object that can be detected is limited by the naturally occurring scatterers in the breast, such as veins. The frequency range of observations should allow substantial backscatter from the tumor and little response from anything smaller. The smallest detectable tumor size should be on the borderline of the Rayleigh-resonance regions.

This system may also help determine the correct frequency for hyperthermia. For high ratios of dielectric constant between the tumor and its surroundigs, resonances exist not only in the scattering, but in absorption cross-sections, as has been observed for S.A.R. (Specific Absorption Rate) data in human beings. For instance, S.A.R. data shows that doubling the ratio of a/λ_m can increase the normalized absorption cross-section by a factor of ten to one. In most previous calculations for hyperthermia, the bounded geometry of the tumor is generally not taken into account - perhaps because the high-water content tumor is generally imbedded in a similar medium. For breast cancer, the proper frequency for hyperthermia may be selected at the resonance of the tumor to permit heating it more strongly than his surroundigs. These resonances may be at thigher frequencies than those customarily used for hyperthermia. However, the resonanct effects should improve the heating despite the greater attenuation losses.

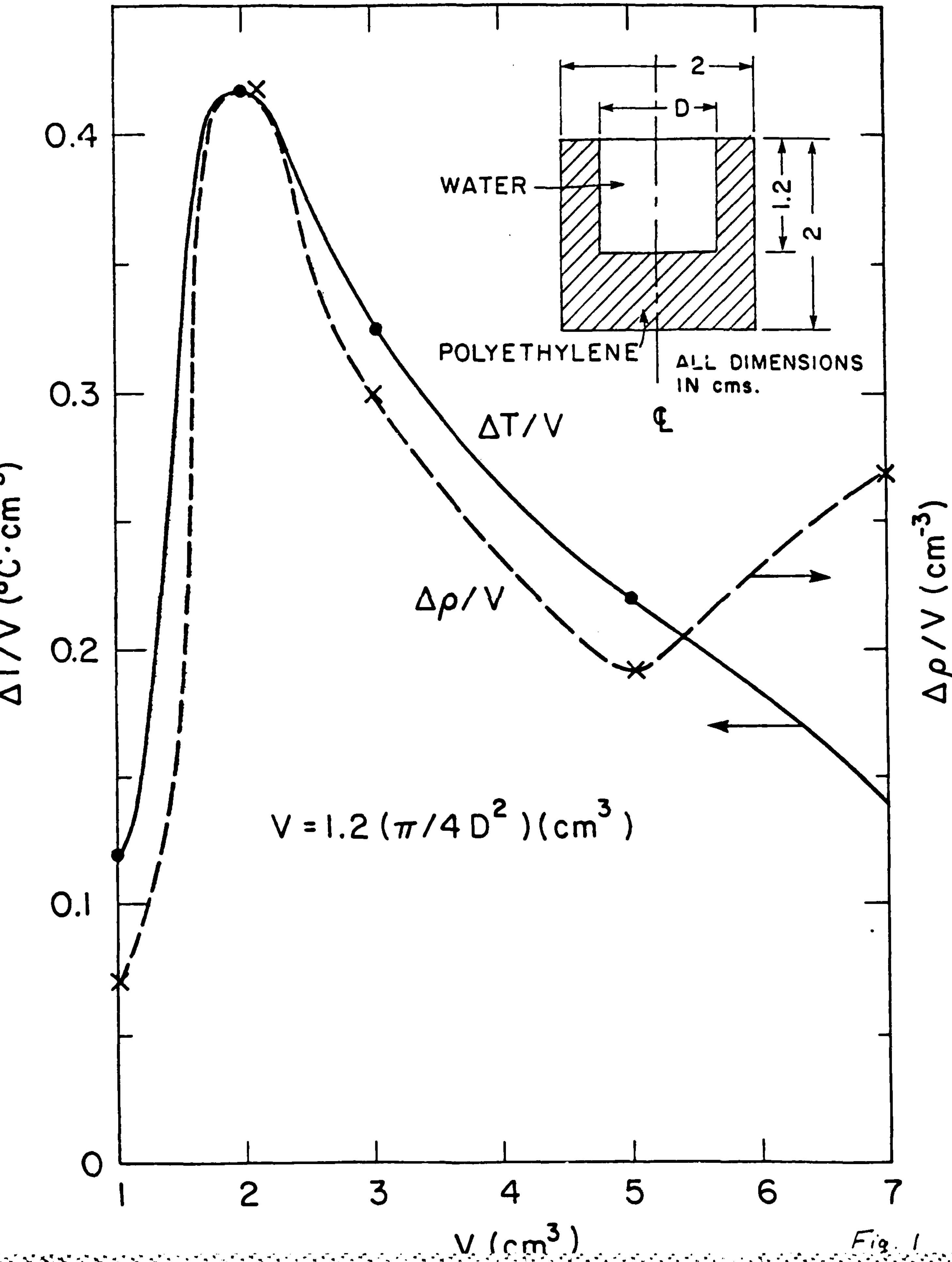
Also, at resonances, intense fields are excited within the object. S.A.R. data shows that, by heating near the resonance realm, hot spots are created within the object, while the use of frequencies above and below this region often leads to only superficial heating on the object's surface. In order to penetrate to the core of the tumor, it would appear that the radiating power used to heat the tumor must be near a resonant wavelength. Although only clinical tests can detemine whether the proper conditions for these resonances occur for breast cancer, dielectric properties of tumors make this a distinct possibility. Even if the resonances do not exist, frequencies in the Mie region would be superior for differential heating to those in the Rayleigh region.

Our proposed meaurements might clinically determine the position of these resonant peaks and the corresponding optimum frequency for hyperthermia. Since the backscattering and absorption resonances often coincide, by finding the frequency where the maximum resonance occurs for the scatter, we might deduce the correct resonant absorption frequency. Preferably, by including a variable filter within a scanning radiometric system, we could take thermographic and reflection readings across several frequency bands. Tumors within the breast are usually hotter than their surrounding tissue. Since a good emitter is a good absorber, the frequency band with the hottest thermographic response might be the approptiate region for hyperthermia.

In tests to determine the validity of these concepts, we used the idea of reciprocity that the absorption cross-section of a heated volume is directly related to the radiometric response. Radiometric tests were conducted by heating the five polyethylene cylinders filled with water to 28°C above ambient. Each cylinder was placed successively in the near field of an open-ended waveguide antenna and reflection and microwave temperature readings were taken. Figure 1 plots the volume of water in each cylinder versus the normalized change in reflection and temperature readings attributable to the water. Although our radiometer averages the thermal emission over its 500 MHz frequency band (2.75 to 3.25 GHz), there is a large resonance between the smallest and the next larger cylinders (1 and 2 cubic centimeter of water, respectively) in both temperature and reflection. By increasing the volume of water by only a factor of two, the radiometric response increases almost by a factor of ten.

As a second test, we put each of the five cylinders into a microwave oven working at 2.45 GHz and measured the rise in water temperature for each volume for twenty seconds of microwave heating. The fields within the microwave oven are not plane waves but the existence of the absorption resonance is apparent once again by the rise in temperature for the 2 cc vial compared to the 1 cc vial as shown in Figure 2. Other preliminary tests in the bistatic mode substantiate the trend. The bistatic cross-section of the 1 cc vial at 2.6 GHz was substantially less than at 3.8 GHz.

We conclude that radiomety could serve to detect and evaluate tumors in the breast by examining three different types of data - thermography, reflection and bistatic scattering - which can all be measured with similar equipment. The newest of these methods, bistatic scattering, offers promise for finding smaller tumors at greater depths than previously possible. Multi-spectral measurements could be more informative than those at a single frequency. The concept of resonance might be applied to the detection and hyperthermia treatments of breast tumors.



2
D
WATER
1.2
2
POLYETHYLENE
ALL DIMENSIONS
IN cms.
℄
ΔT/V
Δρ/V
V = 1.2 (π/4 D²)(cm³)
ΔT/V (°C·cm⁻³)
Δρ/V (cm⁻³)
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
V (cm³)

Fig. 1

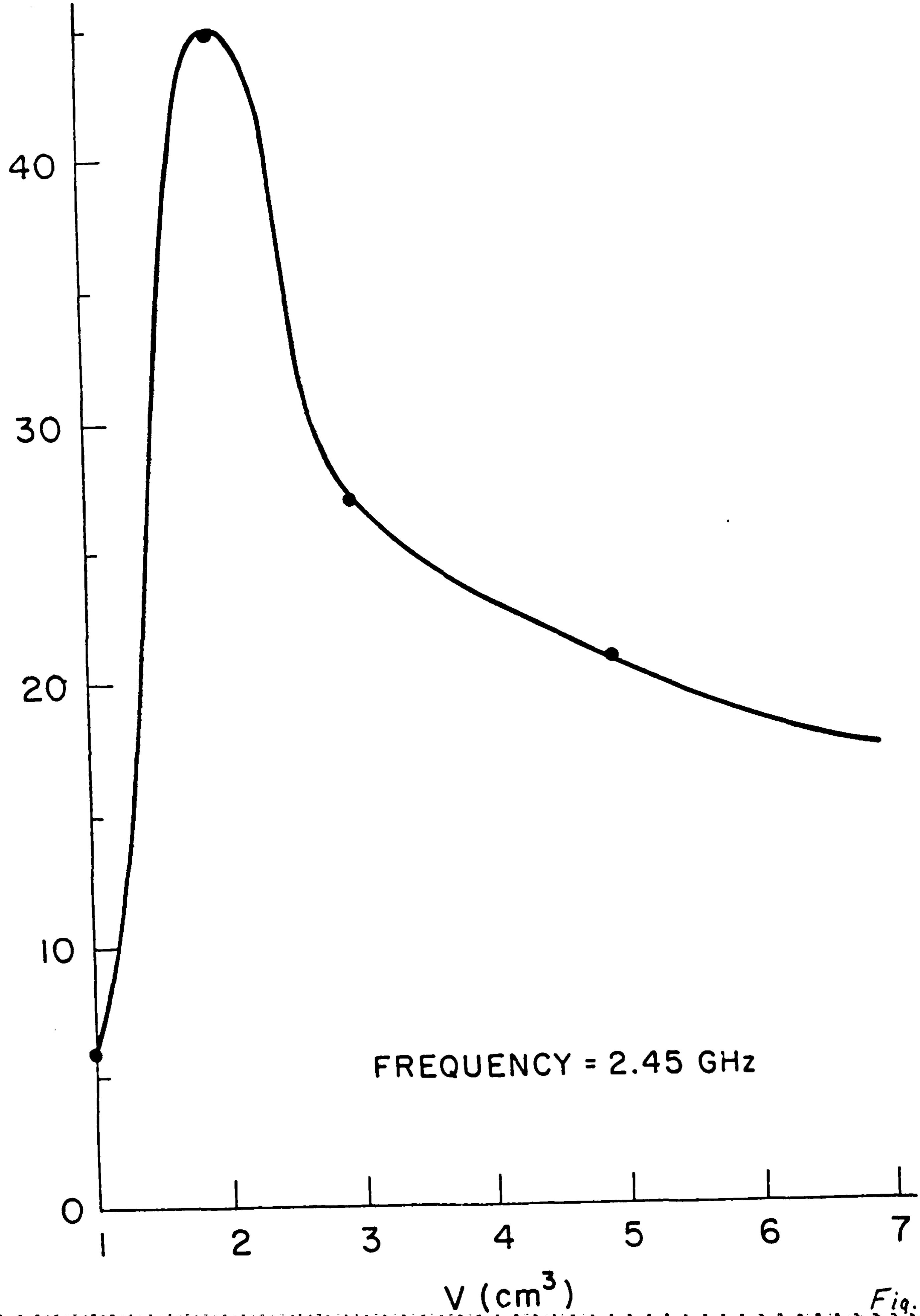


Fig. 2

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