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# The Great Microwave Education Opportunity of the Great Seal Bug (also known as “The Thing”)

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**Abstract** — Are my students too focused on textbooks? Do they seem passive during practical exercises? Am I struggling to engage them effectively? These are common concerns among educators. But how can I spark students' interest in microwave electronics? This paper reports. In this paper, we explore an innovative approach to addressing these challenges: leveraging the allure of espionage history and microwave technology to transform classroom learning. Through a captivating narrative centered around the discovery of a covert spy microphone hidden within a wooden replica of the Great Seal of the United States, we delve into the intricacies of microwave technology, from its principles of operation to its applications in modern communication systems.

**Keywords** —coaxial resonators, microwave engineering, education

## I. INTRODUCTION

August 1945, USSR. The Third Reich has now fallen, and the American ambassador in Moscow meets with a delegation of Soviet scouts as part of strengthening diplomatic ties between the USA and the USSR. As a sign of friendship, the children present him with a magnificent wooden replica of the Great Seal of the United States of America, carved by their own hands. Delighted by this impressive piece of maple wood, the American ambassador hangs it in the sitting room of his residence, Spaso House in Moscow (fig.1).

We are now in 1951 and 1952, Moscow, USSR. English and American voices are heard on Soviet radio bands by embassy employees tasked with surveillance. The US State Department conducts thorough searches of the embassy and Spaso House, leading to the discovery of a bug hidden inside the Great Seal sculpture (fig. 2).

The spy microphone, described as highly advanced according to reports of the time [1], did not have its own power source and was not connected by wires. Instead, the device passively reflected the powerful radio signal from outside, which illuminated it from a NKGB station (\*\*НКГБ:\*\* Народный Комиссариат Государственной Безопасности, People's Commissariat for State Security, later renamed KGB). This principle of retro-modulation gave the bug a practically unlimited lifespan and allowed Soviet agents to obtain valuable information during the tenures of three successive American ambassadors.



**SITTING ROOM** was occupied during Moscow Conference by Secretary of State Marshall, who is shown above writing at desk. Marshall often dined alone here, liked the casual arrangement of the furniture, which contrasts with the balanced décor of the Spaso anterooms (below).



Fig. 1. (a) Image from an American report, covering Secretary of State George Marshall's visit to Moscow in March-April 1947. The Great Seal sculpture is still hanging on the wall [3] of the room, which is likely located at the corner of the south and west facade [4]. (b) Map of Moscow in 1951 [5] showing Spaso House in the center and the numerous surrounding buildings, one of which likely served as a listening post.



Fig. 2. Replica of the Great Seal of the United States of America (56 cm in diameter) with the location of the spy microphone (23 cm long), commonly referred to as "The Thing," "The Great Seal Bug," or "Endovibrator"

Reconstructed by the IMS laboratory in Bordeaux, following the declassification of a technical report from the FBI in 2019 [1], the spy microphone brings together all the ingredients of a pedagogical success story: the elegance of its operating principle (microwave cavity with a resonance frequency varying according to the position of the microphone membrane), the type of signals transmitted (amplitude Modulation), and even instrumentation (variation of reflection coefficient ( $S_{11}$ ) of the cavity according to time), and its application for espionage continue to generate great interest and engagement from students.

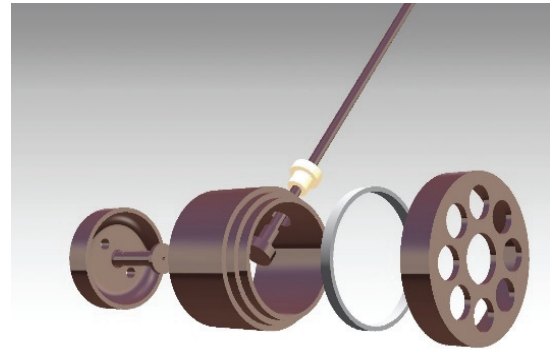


Fig. 3. Exploded view of the spy microphone. The metal membrane is not depicted.

## II. OPERATING PRINCIPLE

The microwave cavity was replicated in the IMS laboratory's mechanical workshop following the original dimensions (fig. 3) [1]. Once connected to an antenna, it behaves like a variable-frequency bandpass filter. At a given cw frequency excitation, the device ranges from a state where all the energy is absorbed in the cavity to a state where all the energy is reflected towards the antenna. If the microphone membrane varies these two states based on acoustic excitation, the illumination signal is modulated by reflection, meaning that the reflection coefficient (and thus its delta RCS, Delta Radar Cross Section [6]) varies over time according to the principle of

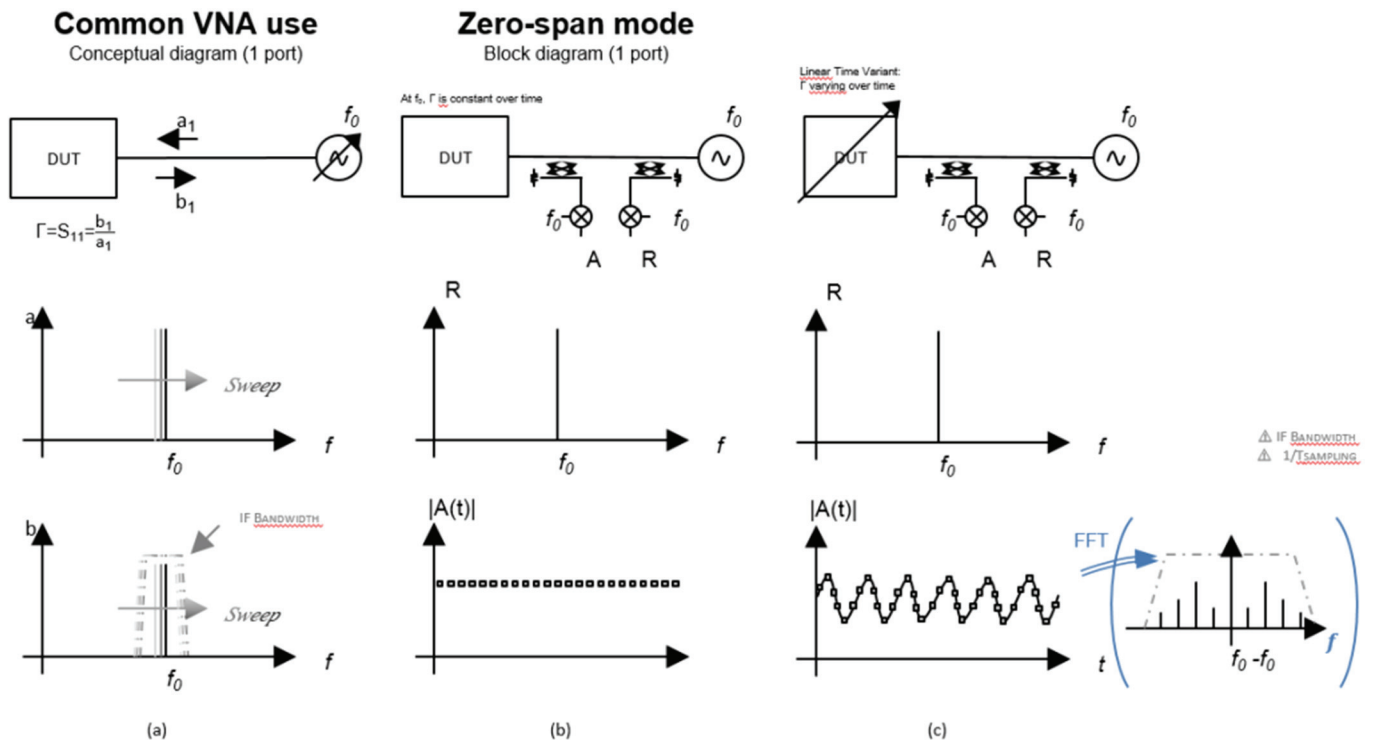


Fig. 4. Measurement principle with network analyzer [9]. Top row: diagram of the measurement performed by the analyzer. Middle row: absolute measurement of the incident wave. Bottom row: absolute measurement of the reflected wave. (a) Measurement in "SWEEP" mode of a time-invariant device, (b) Measurement in "ZERO SPAN" mode of a time-invariant device, (c) Measurement in "ZERO SPAN" mode of a time-varying device.

amplitude modulation (figure 5b) [7]. The device is completely passive and requires neither batteries nor a radiofrequency energy capture and rectification device, as systematically implemented today in RFID sensors [8].

### III. MEASUREMENT PRINCIPLE WITH NETWORK ANALYZER AND REMOTE ANALYSIS

Unlike the listening devices of the time, which separately used a source and a radiofrequency receiver, we use a network analyzer (VNA) with students in a specific configuration.

The classic operation principle of a VNA is described in figure 4a. The internal source generates a wave  $a_1$ , which is applied to the device under test (DUT). The impedance mismatch between the VNA's  $50\Omega$  and the DUT's impedance will give rise to a reflected wave  $b_1$ , which can also be seen as an output wave. The VNA separately measures waves  $a_1$  and  $b_1$  for each frequency and calculates the ratio between them to determine the complex value of the reflection coefficient (parameter  $S_{11}$ ). Usually, the network analyzer sweeps frequency  $f_0$  between two limits (START and STOP frequencies): this is the "SWEEP MODE".

From a hardware point of view, the two waves are partially extracted by couplers, frequency-translated (down-converted), and sampled. Conventionally, receiver 'A' measures the image of wave  $b_1$ , and receiver 'R' measures the image of wave  $a_1$ , as indicated in the diagram in figure 4b, where the load typically has a constant reflection coefficient at a given frequency (case of a device invariant over time). In such a case, the reflected wave measured by receiver A is of fixed frequency. In zero span mode (ZERO SPAN, or sometimes also called CW mode), the frequency sweep is disabled. The VNA then no longer plots amplitude versus swept frequency but plots the amplitude (or phase) of the received signal versus time (fig. 4b).

When a time-varying device is measured (as in the case of the spy microphone), the reflected wave  $b_1$  is no longer of a single frequency but modulated (fig. 5b). It contains many components around the initial "carrier" frequency  $a_1$ , as well as its harmonics. If the frequency band occupied by the modulation is narrower than the bandwidth of the IF filter (Intermediate Frequency), the temporal variations of the signal will be captured by receiver A in ZERO SPAN mode. A simple FFT of the signal then allows retrieval of the entire spectral content of the voice and even determination of the depth of modulation (AM). However, it is important to note that acquiring points in the time domain may lead to aliasing, which should be avoided. It is in this aspect and in the number of memory points that the network analyzer shows a true limitation compared to a dedicated heterodyne radio receiver.

In the context of remote measurement, the VNA is no longer directly connected to the cavity but through two intermediate antennas (fig. 5a). This raises a classic RFID problem: the signal emitted at  $f_0$  is reflected not only by the transponder but also by the entire environment (table, floor, wall, etc.), while the retro-modulated signal by the time-varying device is extremely weak. It is therefore necessary to implement a high-pass filtering after demodulation/frequency translation to reduce the amplitude of the "carrier". This last operation is

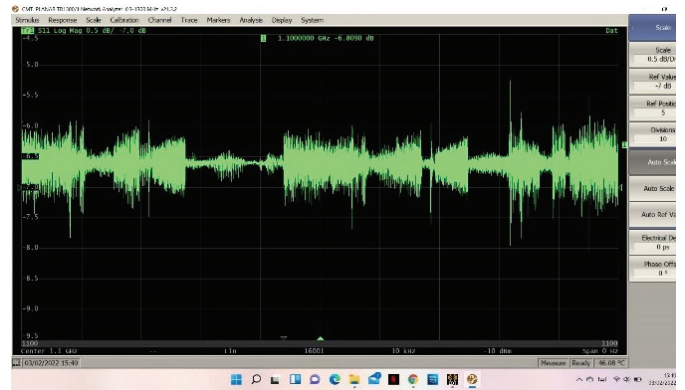


Fig. 5 (a) Wireless setup consisting of a computer controlling a network analyzer, with port 1 connected to a directional antenna. In front of this antenna is the resonant cavity and its antenna, which modulates the reflection of the RF signal based on the measurement of the audio signal captured by the cavity membrane. (b) Visualization of the signal in Zero Span mode (a function of the VNA that can be interpreted as amplitude demodulation).

performed by a Python program that retrieves the ZeroSpan data from the VNA via SCPI queries, filters the temporal signal, and sends it to the computer's sound card (fig. 5b).

### IV. EDUCATIONAL APPLICATIONS

The objective is to propose a pedagogical challenge to students to measure (remotely) the audio signal captured by the microphone. This objective is adapted to the level of education:

- For BUT GEII level (second year of university), the goal is to measure the amplitude-modulated signal using a network analyzer by measuring parameter  $S_{11}$  in zero-span mode, and then extracting the depth of modulation.

- For Master level, the objective is to characterize the device as if it were a mixer where the local oscillator would be the wave at  $f_0$ , the intermediate band signal would be the acoustic wave, and the radiofrequency signal would be  $b_1$ . It is then necessary to decouple the excitation frequency and the analysis frequency on the VNA using the "Frequency Offset" mode [8].

- For BAC+3 to BAC+5 (or even short doctoral training): As part of a project course, students are also invited to reproduce a low-cost DIY version of the Soviet device. This achievement requires reverse engineering, particularly understanding the critical aspects of the device's operation.

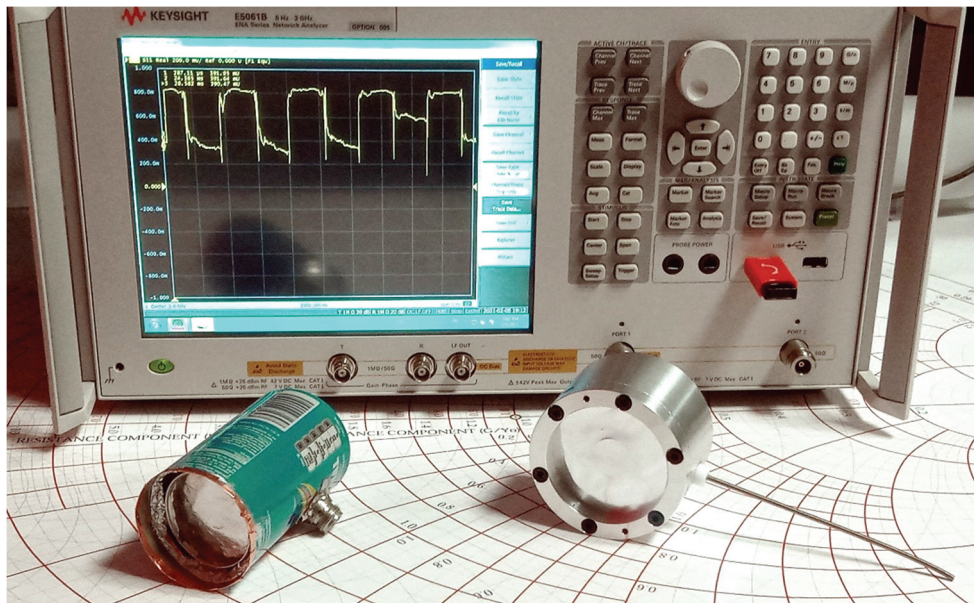


Fig.6. Measurement of  $S_{11}$  in Zero Span mode using the network analyzer of the device built by students from a soda can and kitchen aluminum foil: During the measurement, the membrane is alternately pressed or disconnected from the metal rod constituting the coaxial cavity.

The key parameter being the quality factor of the microwave resonator, and thus the losses of the materials used. Figure 6 shows a student version of the coaxial cavity resonator membrane sensor made from a food can.

## V. CONCLUSION AND PERSPECTIVES

In addition to the proposed practical work, this topic has also been covered by two supervised projects and two internships to support the reproduction of devices and measurement strategies. The objective in all cases is to leverage the aura of the spy microphone as a motivational lever to lead students towards new horizons!

Finally, let's share an experiment that is currently underway this year: within two Bordeaux IUTs, a team of students from the "Book" department has been paired with a team of students from the GEII "Electrical Engineering" department, with the ambition of building an exhibition on wireless technologies from the early Cold War era. In this project, literary students are responsible for designing the scenography and highlighting the historical and literary aspects. They also act as clients for the electronic students who must provide functional demonstrators. This client-supplier role-playing game does not assign a role to the teacher (except as an advisor) but empowers students by placing them in front of their deliverables commitments, without the safety net of "working in a vacuum" often felt in school environments. Once developed, the exhibition will be traveling from library to library across the local territory to serve as a vehicle for the dissemination of scientific and electronic culture within society.

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