Mario Calamia, Giorgio Franceschetti, Monica Gherardelli

From 1922 to today: the Radar, an Italian story too

Dal 1922 ad oggi: il Radar, una storia anche italiana

Abstract
In June1922, in a historical conference held at the Radio Institute of Electric Engineers in New York, Guglielmo Marconi suggested, citing the Hertz's studies, that a metal object can backscatter an electromagnetic wave and thus this event can reveal the presence of a distant object. In the early 1930s, Marconi verified that the radio link between the Vatican State and Castelgandolfo was disturbed by the few cars passing on the roads. Ugo Tiberio was the first researcher in Italy who picked up Marconi's idea and in 1934 proposed to the Italian Navy the construction of a device, with the aim of qualitatively and quantitatively verify this intuition. Tiberio was able to derive the radar equation on the basis of theoretical speculations, supplemented by experimental tests. It was the late '30s and since then, huge technical and financial resources had been used and results had been exceptional. In many countries confidential studies on Radar were conducted and Sean S. Swords had the merit of having described them objectively in his book *Technical history of the beginnings of radar*, published in 1986. In this book the role played by Italy is widely documented, with the addition of the word "perhaps". Our task is to remove that "perhaps" on the basis of documents found in subsequent years.

Sommario
Nel giugno del 1922, in una storica conferenza tenuta al *Radio Institute of Electric Engineers* di New York, Guglielmo Marconi ipotizzò, citando anche gli studi di Hertz, che un'onda elettromagnetica potesse essere riflessa da un oggetto metallico posto a distanza e quindi potesse rivelare la presenza dell'oggetto. Nei primi anni '30, Marconi notò che il collegamento radio tra il Vaticano e Castelgandolfo veniva disturbato dalle poche auto che transitavano. Fu Ugo Tiberio il primo in Italia a raccogliere l'idea di Marconi e a proporre nel 1934 alla Marina Militare Italiana la costruzione di un apparato per verificare qualitativamente e quantitativamente

l'idea di Marconi. Tiberio ricavò l'equazione del radar sulla base di speculazioni teoriche, integrate da prove sperimentali. Siamo alla fine degli anni '30; da allora ingenti mezzi, scientifici, tecnici e finanziari, sono stati impegnati e i risultati ottenuti sono stati eccezionali. In molte Nazioni furono condotti studi riservati sul Radar e Sean S. Swords ha il merito di averli descritti con obbiettività nel suo libro *Technical history of the beginnings of radar*, pubblicato nel 1986. In tale volume c'è già riportato il ruolo avuto dall'Italia sulla base della documentazione in suo possesso, con l'aggiunta della parola "perhaps". Il nostro compito è stato quello, sulla base di documenti ritrovati negli anni successivi, di cancellare quel "perhaps".

Introduction

The Radar is a multidisciplinary device. A transmitter, by means of an antenna, launches into space electromagnetic wave packets which, when an obstacle is encountered, are reflected and revealed by a receiver.

In June 1922 during a historical conference held at the Radio Institute of Electric Engineers in New York, Guglielmo Marconi thought that an electromagnetic wave could be reflected by a metal object placed at a certain distance and therefore its existence could be disclosed [1]: «Before ending my speech, I would like to mention another possible application of these waves which, if successful, could be of great help to seafaring. As Hertz first showed, electric waves can be fully reflected by conducting bodies. In some of my experiments I observed the effects of both reflection and deflection of these waves by metallic objects placed miles away».

In the early thirties, while he was trying the link between the Vatican and Castelgandolfo in order to realize the Vatican Radio which started on February 12th, 1931, Marconi got confirmation of his insight as expressed in the aforementioned conference. The few cars running along the road to Castelgandolfo disturbed the radio link. And so, he said [1]: «It seems to me that it could be possible to design devices through which a ship could radiate or project a divergent beam of these rays in every desired direction. These rays, if they encounter a metallic object, such as another boat or another ship, could be backscattered to a receiver, shielded by the local transmitter and placed on the same ship where the transmitter is installed and then immediately reveal both presence and detection of the other ship, also in event of fog or poor visibility. Another great advantage of such a device would be as follows: it could inform about the presence and detection of any ships, even if the latter were devoid of any type of radio».

The thirties of the twentieth century

In those years, studies began to explore in many countries the possibilities and insights shared by Guglielmo Marconi. Meetings between technicians and scholars took place, to share experiences, even if the confidential nature of such activities, essentially carried out in military fields, prevented from openly discussing issues, which is something Science generally requires.

In Italy, Ugo Tiberio was the first to collect Marconi's legacy of ideas. In 1935 he proposed to the Italian Navy his *Study on the possibility of exploiting for military aims the effects of reflection produced by ultra-short waves* (Tiberio, 1936); this study was meant to build a device able to provide a solid evidence base to Marconi's insight, both at a quantitative and qualitative level. The first page of the manuscript is shown in Fig. 1. Tiberio derived the equation of the radar on the basis of theoretical speculations, supplemented by experimental evidence. The buildup of the first operational devices was due to the work of both British and American forces who got involved thanks to the strength of their organizations and the availability of huge financial means.

The time frame is situated in the first years of 1940; since then, huge technical and financial resources have been committed and the obtained results have been impressive. The work of Ugo Tiberio has been widely known and often discussed in the Italian scientific circles and yet the feedback on it from qualified press was quite limited. The reason for that had to do with the Navy which had classified as SECRET all the related research activities carried out at *Regio Istituto Elettrotecnico e delle Comunicazioni di Livorno* (RIEC). The only paper on the subject was published by Ugo Tiberio in May 1939 on *Alta frequenza* journal under the title "Measurement of distances by means of ultrashort waves (Radiotelemetry)" (Tiberio, 1939).

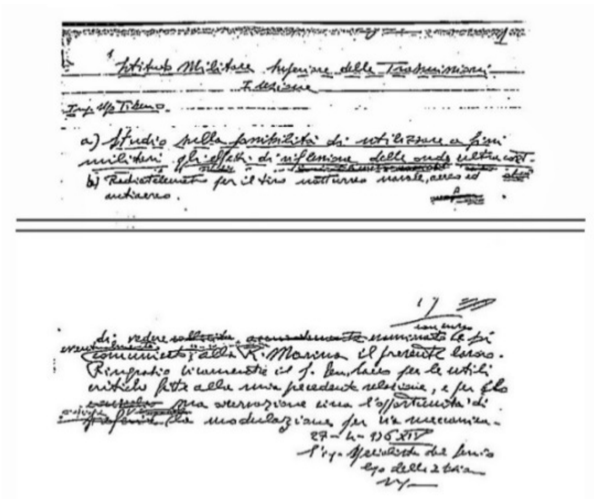


Fig. 1 – Details of both the first page (upper part) and the last one (lower part) of the contribution Prof. Ugo Tiberio proposed to the Italian Navy. Out of the first page, the title has been extracted; while out of the last one, the final part with a date.

Only since 1948, Ugo Tiberio began to publish the results of the impressive work developed in Italy on *Proceedings of the IRE*, on *High Frequency* and on *Maritime Magazine*. In fact, when in 1985 the Italian Navy was invited to the International Conference *The History of radar development to 1945*, the contribution the Navy presented was "The History of the Italian radio detector telemetro" written by Mario Calamia and Roberto Palandri (Calamia and Palandri, 1987). Fig. 2 depicts the first page of the proceedings which were distributed to the Conference attendees. Unfortunately, Ugo Tiberio, who had worked so hard to achieve scientific comparison among different experiences carried out in various countries, had died a few years earlier.

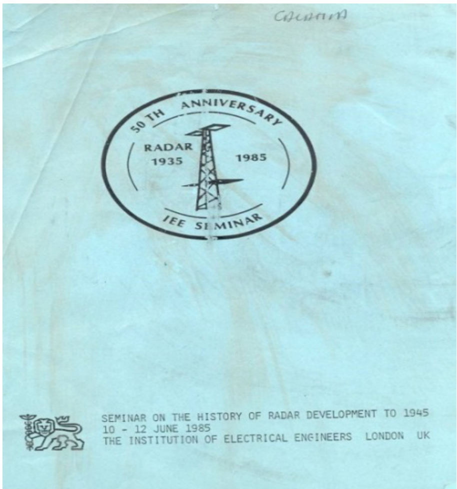


Fig. 2 – Cover image related to the preprint of 1985 International Conference "The history of radar development to 1945", celebrating the 50th Anniversary Radar (1935-1985).

The London Conference in 1985

Ugo Tiberio died on 17th May 1980. Already in the '60s, against radar claims advanced by many, to be the first ones in designing a system with radar capabilities, Tiberio had fought for a scientific comparison on radar activities, carried out in several countries since the '30s onwards. Yet, it was not until 1985 that the London Conference was promoted by Ugo Tiberio himself.

There had been an article in September 1977, written by Robert Page and titled "Monostatic Radar (Who, What, Where, Why, When, and How)", published on *IEEE Transaction on Aerospace and Electronic Systems* (Page, 1977). This paper had triggered the reaction of Ugo Tiberio who in March 1979 wrote a note titled "Some Historical Data Concerning the First Italian Naval Radar", published again on the same *IEEE Transaction on Aerospace and Electronic Systems* (Tiberio, 1979).

With this note Tiberio highlighted some historical mistakes in Page's article and he recalled all the work carried out in so many countries, Italy among them, while wishing a serene discussion to stress all the results obtained in so many countries.

Ugo Tiberio's plea was not in vain, if in March 1980 Harold W. Shipton of the Washington University of St. Louis, Missouri (USA), wrote, as always on IEEE Transaction on Aerospace and Electronic Systems, a short note bearing a significant title: "Radar History: the need for objectivity" (Shipton, 1980). The note began with the sentence: «Dr. Tiberio's appeal for an objective history of radar is apt and timely».

Then, the London Conference occurred, and Ugo Tiberio could not attend it, though he had fought so long to have it.

Many historians continue to ignore the event where for the first time after the war, all the countries which had contributed to the development of any radar system, could document the work done so far. Many cite the book by Sean S. Swords (Swords, 1986), a book of high historical value, but its importance is enormously increased if you link it to the London Conference, to the discussions made at that conference and the (successful) attempt to cancel the most significant and documented contribution, the one by Swords.

As already mentioned, at the 1985 International Conference: The history of radar development to 1945, celebrating the 50th Anniversary Radar (1935-1985), Italy took part in it with a paper officially authorized by the Navy High Command, "The history of the Italian radio detector telemetro", edited by Mario Calamia and Roberto Palandri, who was by then Director of the Radar and Telecommunications Institute "Giancarlo Vallauri" of the Italian Navy (MARITELERADAR).

The event allowed and made clear some aspects:

– it became internationally acknowledged that the Radar's date of birth, according to current meaning, was 1935;
– the role Italy played in that context had been crucial;
– the role played by both Guglielmo Marconi and Ugo Tiberio has been formally recognized.

The London Conference was an extremely important milestone in the history of Radar. Representatives from all over the world were invited to participate: 38 contributions were made. They were from the countries which in some way had contributed to the birth and development of Radar and Italy was one of these countries.

The general opening report of the conference was entrusted to Swords, professor at Trinity College in Dublin, so as to overcome the underlying dispute between British and American scientists about the claimed priority in developing Radar. As it would turn out later, Swords had collected an impressive bibliography, he had read up a lot and extensively gathered information; yet his introduction to the Conference, *The beginnings of radar*, was very lean, almost like a notarial deed: he reported news of what had been done in different countries, based on reliable reconstructions.

Swords devoted to the Italian activities 19 lines of the 200 lines the opening speech was made of.

At the beginning of the Conference, pre-prints had been distributed; they had various reports and many participants in the Conference kept them, including one of the authors of this current paper. Activities ended with much discussion and some dissatisfaction. The report by Swords was a fair record of the historically outlined situation. Attendees waited for Conference Proceedings.

More than a year passed by without anyone knowing anything about it.

More than two years went by and finally the proceedings collecting all the papers presented at the conference appeared: there was no record of the general opening report made by Swords. It had been replaced by the one written by the English Russel W. Burns; this went exactly in the direction of what had been tried to avoid in organizing the 1985 Conference. The report by Russel W. Burns was certainly more articulated than Swords' previous version, but it had the Italian contribution (and not that only) greatly reduced to only five lines out of 28 pages, not to mention the use of the sentence "it seems".

Meanwhile, Swords in 1986 published perhaps the most complete book on the history of Radar: *Technical History of the beginnings of Radar* (Swords, 1986). This publication is of great importance to get a complete overview on the history of Radar. It is a technical history and for this purpose Swords studied an impressive number of sources, as many as 324 are the ones mentioned. Thanks to the extensive and exhaustive treatment of the subject, he was able to reconstruct the contribution of each and every nation to the development of Radar, in a way not conditioned by other factors. The first edition of this book dates back to 1986; therefore, there is no doubt about Swords being already familiar with this subject at the 1985 London Conference. His brief but accurate report for the cited conference was not the result of rustled up news, but the synthesis of a long and well documented work.

As said, the volume by Swords is a technical history about the origins of radar and in this history, Italy is accounted for, with the work of many scientists, researchers and industry operators, starting with Ugo Tiberio who is properly the most quoted in this book.

What follows is a passage taken from Swords' publication, Chapter 2.3 "Radar range equation": «Ugo Tiberio of Italy was perhaps the first radio scientist to study experimentally and theoretically the reradiation properties of targets. In 1933 Guglielmo Marconi, while testing a microwave installation for the Vatican between the Vatican City and Castel Gandolfo, observed a beat effect from nearby moving objects. Conscious of the importance of the phenomenon, he gave a demonstration to some senior military staff, among whom was General Luigi Sacco. General Sacco requested Professor Ugo Tiberio to make a report on "The equation of radiotelemetry". The study was completed in 1935 and resulted in the paper "The measurement of distance by means of ultra-short waves (wireless range-finding)"» (Tiberio, 1939).

Swords himself made use of the word "perhaps". His sources are trustworthy and reliable, but they lack the historical seal of a publication with a certain date on it.

The retrieved manuscript (1996)

A turning point in the knowledge of the events related to the Italian radar is represented by a date, aiming at cancelling the word "perhaps" as well. A manuscript by

Ugo Tiberio was found in 1996, after the death of his wife Bianca, when Tiberio's sons were reorganizing the papers of their father. Other documents were found later. These documents allow validation on the hypotheses done about the work carried out in Italy and anticipated with foresight by Swords in his book.

So much it could be said about this manuscript. Premises are clearly set for radar developments in the forthcoming years.

But here we must first ask two questions:

1) the problem of possible radar operation;
2) the problem of the construction of the relevant radar installation.

As to point 1), Ugo Tiberio has undoubtedly a scientific priority which has been historically confirmed. We should not forget that Marconi and others after him had spoken of "electromagnetic disturbances" caused for example by nearby moving objects intersecting an electromagnetic wave. But the problem of using this beat effect was related to the possibility of measuring it, which is to say the availability of a sufficient level of return signal to be received and revealed. This return signal was related to the features of the target and its ability to reradiate. In his manuscript Ugo Tiberio classified the problem of radar "radio telemeter", he wrote about the relationships among different parameters, the "equation of radar" and eventually focused on its main parameter, which he called the "reradiation" factor of the target. After he had collected all the available data in literature, he asked to go to the RIEC to test experimentally the ability to reradiate a target and measure it. He wrote (Tiberio, 1936): «I tried also to perform the calculation (of the reradiation ability of a target) on a purely theoretical perspective, but I consider of no use to report on it, because the deduced values are very high, and it is not safe to rely on them». This is not theoretical speculation; it is the normal way a great researcher seeks experimental validation to confirm his hypotheses.

On such grounds the first installation he developed in 1936, the so-called EC1, was meant precisely to verify the validity of the equation raised to the fourth power, which is the equation of radar he theoretically conceived. Not only he developed the device, but he also created a kind of target sample that was installed on a speedboat moving about in front of the Naval Academy in Livorno, to get quantitative answers.

Thus, he introduced the idea of target modeling, namely the idea of "the equivalent radar section" which will involve next generations so much.

The second aspect deals with an industrial involvement linked to economic factors and political decision-making processes. Italy as well had built her own devices and there is a lot of photographic evidence of it. For sure, there were delays due to policy decision and improper technical assessment of the ground-based radar data potential by the relevant policy making authorities. In his manuscript Ugo Tiberio had already defined the role to be assigned to Industry in the radar construction.

Both UK and USA could fully understand the role the radar could play on a military level; thus, once evaluated its potential, they deployed huge technical and economic resources for its development. Not even the first atomic bomb would have mobilized equal resources. Therefore, it would have been too difficult to compete with such capacities on an industrial level.

The reconstructed tile work

The book written by Swords is an exceptional document which helps a lot in describing each contribution by different Countries in its historical context.

The manuscript by Ugo Tiberio, found in 1996 and dated April 1936, was a revised edition, as the document itself clearly states, of a previous report and the latter could only date back to 1935, which is to be fixed as the official date of birth of radar. The Italian radar, therefore, was born as an original idea of a man who had devoted himself to the study of a new science, the electronics, after he had studied civil engineering and had obtained a specialization in Electrotechnics.

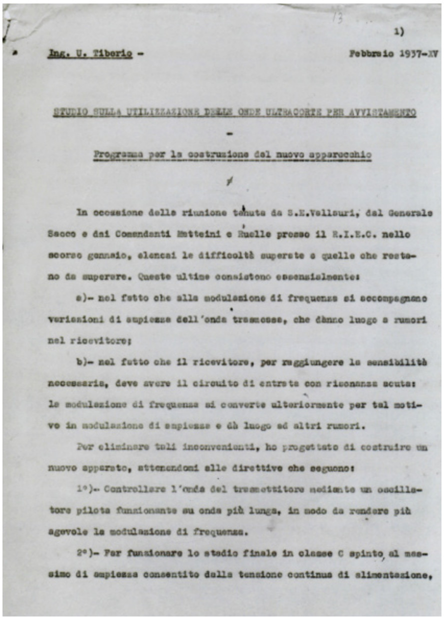
A first reading of the manuscript sheds light on the size of the author, beginning with the title of the paper itself: *Study on the possibility of using the effects of ultra-short wave reflection for military purposes*.

Based on this manuscript, a first prototype was prepared, EC1 and first tests and measurements with it were carried out as early as in 1936. It was a frequency modulated continuous wave radar, at 200 MHz. Results turned out to be encouraging. This is especially the case with reference to the purposes already set, if in February 1937-XV, Ugo Tiberio could write for the Italian Navy High Command a report entitled: *Study on the use of ultra-short waves for sighting. (Program for the construction of a new installation)* (Tiberio, 1937). Fig. 3 shows the first page of this report.

Based on this document dated 27 February 1937, Ugo Tiberio was asked by the Italian Navy High Command to write a report which has not a precise date, but it could be presumably dated back to 1937. This report was entitled *Project of an installation to disclose obstacles by means of ultrashort wave modulated frequency (Radio telemeter)*. Fig. 4 shows the first page of this project (Tiberio, 1937a). It is an extensive piece of work provided with well XIV descriptive tables, no longer available, but fully illustrated in the document which gave the go-ahead for the construction of the second continuous wave installation (EC1 2nd edition, 1937).

This one was different from previous one, mainly because it exploited a superheterodyne receiver, which nevertheless caused some problems in tuning the receiver. However, the work went on, if already in 1937 a 1.70-metre wavelength "pulse device" was developed, namely the EC2, which had to face problems with the transmitting tubes.

These unsatisfactory results with the pulse device can give reason why Ugo Tiberio had opted for the continuous wave solution. To verify the possibility of detecting



1)

Ing. U. Tiberio - Febbraio 1937-XV

STUDIO SULLA UTILIZZAZIONE DELLE ONDE ULTRACORTE PER AVVISTAMENTO

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Programma per la costruzione del nuovo apparecchio

In occasione delle riunione tenute da S.E.Vallauri, dal Generale Sacco e dai Comandanti Matteini e Ruelle presso il R.I.E.C. nello scorso gennaio, elencai le difficoltà superate e quelle che restano da superare. Queste ultime consistono essenzialmente:

a)- nel fatto che alla modulazione di frequenza si accompagnano variazioni di ampiezza dell'onda trasmessa, che dànno luogo a rumori nel ricevitore;

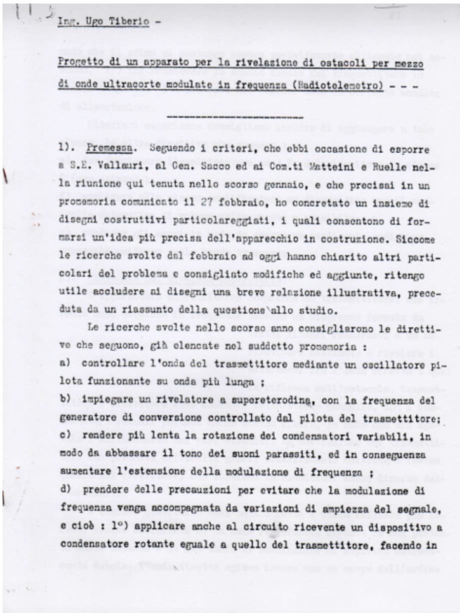
b)- nel fatto che il ricevitore, per raggiungere la sensibilità necessaria, deve avere il circuito di entrata con risonanza acuta: la modulazione di frequenza si converte ulteriormente per tal motivo in modulazione di ampiezza e dà luogo ad altri rumori.

Per eliminare tali inconvenienti, ho progettato di costruire un nuovo apparato, attenendomi alle direttive che seguono:

1°)- Controllare l'onda del trasmettitore mediante un oscillatore pilota funzionante su onda più lunga, in modo da rendere più agevole la modulazione di frequenza.

2°)- Far funzionare lo stadio finale in classe C spinto al massimo di ampiezza consentito dalla tensione continua di alimentazione,

Fig. 3 – First page of the report Prof. Ugo Tiberio wrote for the Italian Navy High Command in February 1937.



Ing. Ugo Tiberio -

Progetto di un apparato per la rivelazione di ostacoli per mezzo di onde ultracorte modulate in frequenza (Radiotelemetro) - - -

1). Premessa. Seguendo i criteri, che ebbi occasione di esporre a S.E. Vallauri, al Gen. Sacco ed ai Com.ti Matteini e Ruelle nella riunione qui tenuta nello scorso gennaio, e che precisai in un promemoria comunicato il 27 febbraio, ho concretato un insieme di disegni costruttivi particolareggiati, i quali consentono di formarsi un'idea più precisa dell'apparecchio in costruzione. Siccome le ricerche svolte dal febbraio ad oggi hanno chiarito altri particolari del problema e consigliato modifiche ed aggiunte, ritengo utile accludere ai disegni una breve relazione illustrativa, preceduta da un riassunto della questione allo studio.

Le ricerche svolte nello scorso anno consigliarono le direttive che seguono, già elencate nel suddetto promemoria :

a) controllare l'onda del trasmettitore mediante un oscillatore pilota funzionante su onda più lunga ;

b) impiegare un rivelatore a supereterodina, con la frequenza del generatore di conversione controllato dal pilota del trasmettitore;

c) rendere più lenta la rotazione dei condensatori variabili, in modo da abbassare il tono dei suoni parassiti, ed in conseguenza aumentare l'estensione della modulazione di frequenza ;

d) prendere delle precauzioni per evitare che la modulazione di frequenza venga accompagnata da variazioni di ampiezza del segnale, e cioè : 1°) applicare anche al circuito ricevente un dispositivo a condensatore rotante eguale a quello del trasmettitore, facendo in

Fig. 4 – First page of the project on Radiotelemetry prepared by Prof. Ugo Tiberio for the Italian Navy High Command.

the weak signal re-radiated by a target illuminated by an electromagnetic wave, the continuous wave radar could be fine; this was the primary purpose of his study (as stated in the title of the manuscript itself). But, when it came to the design of a new installation (see title of the above-mentioned report), a pulse radar would have been more efficient. He had already got some glimpses on this solution, as in the manuscript he had written (Tiberio, 1936): «(omitted)........ In fact, the reception of a weak field (the one reflected by the target) in the event of a strong one (the one emitted by the transmitter) remains virtually impossible as long as the two fields have the same frequency, but it becomes extremely easy if frequencies are different». Thus, the formulation of the principle was as follows: «to take advantage of the time the reflected wave needs in the return path to change the frequency of the transmitter».

But to have time available to change frequency between one transmission and the other, a pulse radar was necessary. And with the change in frequency, Tiberio went beyond pulse radar to project research into more sophisticated radars which would have been designed more than 20 years later. The EC2 model did not give the results hoped for, due to the unavailability of suitable tubes (after few pulses, the cathodes of the tubes belonging to the receiving type were "torn off" by strong anode currents). At this point, the lack of confidence by the Authorities in charge became self-speaking: activities were slowed down, financing reduced and only in 1940 the first EC3 could be assembled. It exploited a Philips power pulse triode, which was normally used in reception and therefore still lacking satisfactory outcomes.

Three years went by, an important gap emerged which made Italy lose her initial lead (1935-36-37). This initial lead must be attributed to the clear approach adopted by Ugo Tiberio both in his manuscript dated back to 1936 and the aforementioned project (Tiberio, 1937a).

After the naval Battle of Cape Matapan, on 30 March 1941, where the radar of the enemy forces had played a role (even if the English version was for sure less evolved than the Italian one), Italian radar activities began again in earnest. This brought to EC3 (second version in 1941) and to a third version of it (same year) which successfully exploited the cavity resonators studied by Nello Carrara at the RIEC. From that moment on, alongside the work carried out by scholars the industrial phase began, which led to the construction of the *Gufo* (Owl) and its counterpart for coastal surveillance, the *Folaga* (Coot).

The situation was definitively compromised when RIEC tasks were devolved to escape bomb attacks and thus records of priceless value and official documents were scattered across various places (Calamia, 2014). As it often occurs, unfortunately much of this material was entrusted to inexperienced hands and went lost; only a small part of it was given back to MARITELERADAR. Ugo Tiberio had kept the documents of his time, and this has allowed to rewrite a piece of this history.

It is necessary to spend few words on the work carried out by the Navy as to the issue of radar. The work of the Navy must necessarily be framed in the time where it took place. The Regia Marina (the Navy of the Kingdom of Italy) had created favorable conditions to conduct a systematic study on the ideas of a young researcher and this had expedited his work. In doing this, the Navy had also to manage some internal conflicts, against the narrow-mindedness of some men rejecting innovation and moored tightly to ideas which will be overwhelmed by events. Yet sometimes man is not up to the task history entrusts him; when these men are gone, history resumes its path and our aim was to acknowledge the positive aspects the Institution could accomplish anyway, despite any contingent negative situations.

To the present day

We will now try to describe how it became possible to change that instrument, born in the emergency conditions of the Second World War, into current radars which enable some incredible scientific missions and deliver us images of great intensity, even from an emotional point of view.

Second World War had given us an instrument which played a fundamental role in the war’s outcomes. But this instrument could be changed to suit more advanced uses in civil applications. Let us therefore identify what the path was like.

Pulse compression (chirp radar)- synthesis of radar signals

The first aim was to discover an increasingly distant target without losing in precision. In the radar range equation, there are two terms: transmitter power in the numerator and receiver sensitivity in the denominator. The former had a limiting factor in the transmission line (waveguide) connecting the transmitter to the radiant energy. Out of this scenario the idea of a multi-channel radar emerged: more transmitters operating on slightly different frequencies and appropriate combination of return signals from target.

From multi-channel radar to pulse compression (chirp radar) it was but a short step: on transmission the radar pulse is stretched and modulated in frequency; on reception the signal is demodulated and then compressed. This increases the received energy for accurate distance measurement, without losing in resolution (Bramanti and Calamia, 1969).

Radar with low noise figure

The receiver sensitivity is another important parameter in the denominator of the radar range equation. Important studies have been conducted on how to improve the receiver sensitivity by means of parametric amplifiers and other low noise amplifiers. It was an extremely important step which enabled the reception of weak signals from stationary satellites, 36,000 km of space (Carassa, 1961).

Radar for the detection of low-level targets

Some war episodes in the 1960s gave evidence that low-level air attacks were disrupting radars. This was evident in the case of tracking radars with conical scanning. The problem was tackled in different ways, until the "monopulse radar" was developed. It consisted of a system of four antennas which allowed the reduction of interfering image signal effect, thanks to a proper combination of received signals (Calamia et al., 1974).

Phased array radar (Synthetic Aperture Radar).

In 1969 the 1st Lunar Mission (Calamia et al., 2020) highlighted some radar deficiencies as to certain types of missions. Programs were set up and gave rise to activities referred to as Earth Observation. Meanwhile, the development of computers allowed both an increasingly rapid data processing and the development of the Synthetic Aperture Radar-SAR.

We consider an airplane on a straight path and on that path, there is a transmitting-receiving system illuminating a target scene on the ground, with a regular frequency of sinusoidal pulses, receiving and recording their echoes. If the N number of transmitted pulses is sufficiently limited, the illuminated area remains essentially perpendicular to the irradiated beam. Besides, if the time delay between the received pulses is erased in the reception processing, this corresponds to an N-element receiving antenna, which can be designed to optimize the antenna power gain.

The SAR has been the key element for the development of satellite observation with an accuracy which could completely revolutionize the notion of Observation from Space. The development of computers has enabled a solid processing and fusion of any SAR design procedure (Franceschetti and Lanari, 2018; Franceschetti et al., 1991; Franceschetti et al., 1991a).

Multisensor data fusion

A brief mention should be made of "the fusion of data" from disparate sensors: radars, active and passive microwave sensors, optical sensors of different kinds.

The multi-frequency and multi-temporal images, obtained by combining and processing multiple images generated by these sensors mounted on the same satellite, made it possible multicolor images of the examined scenario, for a more efficient analysis of the Earth's surface, but its application was not only limited to that. In recent years the Sentinel platform has been used and outcomes are extremely useful, not to mention that the obtained imagery displays an unparalleled beauty. Some significant (though not exclusive) images are reported.

Conclusions

As the authors intended, previous sections of this paper are meant to come full circle to find the truth about the Italian contribution to radar development. The issue had been left open due to different reasons the authors accounted for and ranging from military intelligence to documentation loss and scattering due to war.

The manuscript and the other cited documents give full confirmation of what Swords was able to reconstruct on his own and according to documents he had.

In 1986 Swords wrote in his book what follows: «Ugo Tiberio of Italy was perhaps the first radio scientist to study experimentally and theoretically the reradiation properties of targets».

Our main intention has been that of contributing to cancel the word "perhaps".

The image of Ugo Tiberio, together with the group of researchers working in the second half of the thirties at MARITELERADAR, comes out strongly revalued. Same must be said about the outcomes achieved by the Navy which, by putting in the same Research Centre scientists of tremendous potential, had clearly demonstrated with its most farsighted men to be able to anticipate time.

The purpose of the last section is to highlight how scientists and technicians have worked together in these first hundred years, as to that insight dated back to June 1922. The discussion cannot and was not intended to be exhaustive, but it has simply tried to show the starting point, the current outcomes already achieved and the direction which we should proceed towards.

Acknowledgements
We would like to thank Paolo and Roberto Tiberio, who made available their father's manuscript and other documents. We also express special thanks to the Italian Navy for always supporting research and initiatives aimed at establishing historical truth.

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