HEDY LAMARR AND FREQUENCY HOPPING

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ABSTRACT

This paper reconsiders the question of the role of Hedy Lamarr in Frequency Hopping technique, taking as a starting point the historical and descriptive accounts on the items under consideration. By way of illustration, the paper examines the pertinence of Frequency Hopping and Spread Spectrum mainly in the descriptively-oriented manner and based on the literature on the subject. This paper is built around six parts. The paper opens with an introduction that sets the scene. It sketches out the scientific contribution of Hedy Lamarr. The second part provides some introductory remarks on Hedy Lamarr as an inventress. The third part recasts certain aspects of Hedy Lamarr's contribution to the invention of Frequency Hopping by moving from the centre and working outwards. The fourth part is a sketchy exercise of simple structures serendipitously leading to complex ideas and describing Spread Spectrum and Frequency Hopping. The fifth part is more empirical in nature in that it outlines some linguistic aspects of Frequency Hopping Patent by means of first and foremost structural linguistic analysis. A brief discourse analysis was aimed to show that some language items may be used to account for this discourse type, or text type, i.e. the analysed patent text. In this way, the analysed historical-descriptive engineering and linguistic aspects are brought together to elucidate the overall contribution of Hedy Lamarr in the former and current domain of Frequency Hopping.

Keywords: Hedy Kiesler Markey – Hedy Lamarr, Inventress, Frequency Hopping, Spread Spectrum, Electrical Engineering, Discourse Analysis, Structural Analysis, Patent Discourse, Text Linguistics.

1 Introductory Remarks

Hedy Lamarr was best known for her work in Hollywood during the Golden Age of Hollywood. However, less was known about Hedy Kiesler Markey, the inventress of Secret Communication System that embodies Frequency Hopping. This paper looks at the implications of her invention, her patent and her role in Frequency Hopping and Spread Spectrum, from a descriptively-oriented perspective.

This paper is organised around the following parts. The second part sets the scene by introducing a brief overview of Hedy Lamarr as a beautiful woman, a scientist and an inventress. The third part focusses on Hedy Lamarr's contribution to Frequency Hopping from a dynamic perspective starting

from the centre and working outwards. The fourth part sketches certain aspects of Frequency Hopping and Spread Spectrum from simple structures to complex ideas whilst delving in the electrical engineering literature on the subject in an attempt to provide a unitary descriptive account of these two phenomena. By way of illustration, the fifth part analyses the text of the patent of Hedy Lamarr inspecting merely the linguistic indicators of patent discourse with the help of the structural analysis tools, and certain pertinent ingredients of discourse analysis and text linguistics. The sixth part provides certain concluding remarks.

2 Some Remarks on Hedy Lamarr, a Beautiful Woman, a Scientist, and an Inventress

According to *Jewish Women*: *A Comprehensive Historical Encyclopedia*, Hedwig Eva Maria Kiesler, or simply Hedy Lamarr, was the Austrian film star well-known as an exotic beauty, often represented as a foreign temptress in Hollywood-generated films [1]. In addition to her Hollywood career, she also contributed to the development in the field of wireless communications by inventing a frequency hopping technique. More specifically, she was working towards generating a frequency-hopping radio signal whilst investing efforts to synchronise its frequency changes between a ship or an airplane and a torpedo.

According to the publicly available records, Hedy Lamarr was born Hedwig Kiesler on 9th November 1914, in Vienna. Hedy Lamarr died on 19th January 2000. Lamarr's mother was Gertrude Lichtwitz, also known as Trude Lichtwitz, who came from a sophisticated family in Budapest, whilst Lamarr's father Emil was from Lemberg, Lwów, in the West Ukraine.

Figure 1: The photograph of the actress and inventress Hedwig Eva Maria Kiesler, also known as Hedy Lamarr. The caption from the original document contains the following text: "Actress and inventor Hedy Lamarr in the MGM film The Heavenly Body, 1944." The photograph was provided by the courtesy of the Jewish Women's Archive - JWA.

Both Hedy's parents were Jewish and, consequently, she was registered at birth as Jewish, yet, according to some sources, she remained strikingly tongue-tied about her Jewish identity (see [1]). It was known that her father was the manager of the Creditanstalt Bankverien, and that the family lived on Osterleitengasse in Döbling in Vienna's posh and fashionable 19th Bezirk, and afterwards they moved to Peter-Jordan-Straße, located also in Döbling District.

According to the pertinent literature, Hedwig Eva Maria Kiesler was the only child of Gertrud Lichtwitz and Emil Kiesler, who provided their daughter with the well off and cultured environment. The same source stated that Lamarr often depicted her childhood period as a kind of lost paradise comprising education at the Döblinger Mädchenmittelschule, memorable walks with her father in the Wienerwald, and piano lessons with her talented mother [1].

According to the publicly available sources, Hedy Lamarr started attending Professor Arndt's acting classes in Vienna (see, for instance, [1]). She was so passionate about acting that she wanted to be actively involved in the machinery of the Austria's largest film studio at that time, more precisely, the Sascha Film Studios. Even though she was in love with acting she explicitly pointed out that she wanted neither a Hollywood career nor to become a cinema slave.

Figure 2: The photograph of the actress and inventress Hedwig Eva Maria Kiesler, also known as Hedy Lamarr. The caption from the original document contains the following text: "Hedy Lamarr." The photograph was provided by the courtesy of the Jewish Women's Archive – JWA.

Having attended the acting classes, Hedy Lamarr was formally trained under Professor Arndt In Vienna. Officially, her first appearance was in Georg Jacoby's *Gold on the Street*, originally *Geld auf der Straße* in 1930. She continued her acting career under the auspices of the famed Jewish

theater director, Max Reinhardt, in his stage production of *The Weaker Sex*, and then she appeared as the star of Gustav Machatý's 1933 Czech art film, *Extase*, i.e. *Ecstasy*, which, according to the pertinent literature (see [1]) was best remembered in the film history due to the film scenes "in which the teenage Lamarr runs naked through the woods before plunging for a dip into a lake and simulates orgasm with her lover" (see [1]).

Perhaps the most relevant person to be mentioned is Herr Friedrich "Fritz" Mandl, who was an arms merchant as well as a munitions manufacturer from Vienna, Austria. More often than not, Mandl was described as the third richest man in Austria.

According to the publicly available data, Herr Mandl became obsessed with Hedy Lamarr and wanted to meet her in person. Hedy was said to have adored Mandl's charming individuality and his fascinating personality, even though some gossip sources claimed that this attraction was partly due to Mandl's Brobdingnagian wealth. Clearly, Hedy's parents, both of whom were of Jewish descent, did not approve of this relationship, and ultimately, marriage.

Figure 3: The photograph of the actress and inventress Hedwig Eva Maria Kiesler, also known as Hedy Lamarr. There is no caption in the original document. The photograph was provided by the courtesy of the American Physical Society - APS. APS News, June 2011 (Volume 20, Number 6).

On our assumptions, based solely on the descriptively-oriented literature, the disapproval of Hedy's parents might be the case primarily due to Fritz Mandl's tight connection with Benito Mussolini and Führer Adolf Hitler, but they could not prevent her from marrying Mandl. Ultimately, on 10th August 1933, at the age of eighteen, Hedwig Kiesler married Friedrich Fritz Mandl, who was thirty-three years old.

According to the pertinent literature, Hedy Lamarr married six times and witnessed her career fall into decline, whilst remained remarkably silent about her Jewish identity (see [1]).

Before embarking on her Hollywood career, Hedy Lamarr, that is Hedwig Kiesler, to be more exact, spent some time in Switzerland. More precisely, she spent the winter of 1936/1937 before settling in Paris, as a temporary resort. After that period, she headed towards the USA and Hollywood.

Perhaps the most relevant role in Hedy's life in that period pertained to the sophisticated English gentleman, Reginald Gardiner who introduced her to Walter Wanger. However, it ought to be emphasised that Walter Wanger altered the path of Lamarr's artistic life direction. However, since this paper is not oriented towards that part of Hedy Lamarr's life and career, it is necessary to impose an interpretation on her occupation of an inventress.

From [2], it follows that Lamarr was on the road to observe the clash in Europe from the distance of America. In addition to being in the business of selling war bonds and also serving in the Hollywood canteen, she brought the intellectual property acquired in the Mandl's castle (for instance, see [2]). For one thing, it appears that both Hedy Lamarr and other high-profile Germans and Austrians, obtained "a chance to remind their hosts where their allegiances lay", [2]. In Hedy's own words, "[she] constantly worked at the Canteen and [she] worked hard" [2].

In Hollywood, Lamarr became well-known for the diverse roles she played. It may be, then, that Hedy Lamarr enjoyed the financial security that would enable her to dedicate time to her own experimental interests. It appears, clearly, that this was perhaps the most relevant part in her career from the point of view of science and engineering. More specifically, it was exactly during the war that she persuaded George Antheil, the composer and concert pianist, to collaborate with her on her invention of a radio-controlled torpedo-guidance system, which she labelled "Secret Communication System" [2]. According to the quoted reference, a consequence of the approach to this invention just outlined was that the Secret Communication System became widely known afterwards, and, consequently, represented a lesser item of interest.

In Hollywood, Hedy Lamarr was constantly in the glare of the spotlight, but despite all that, she continued to develop her inventions far from any publicity, almost secretively.

3 Hedy Lamarr's Frequency Hopping: Starting from the Centre and Working Outwards

According to the available data, Lamarr became interested in invention as a child primarily inspired by her father, who was an amateur engineer himself (see [3]). Equipped with her ambition to invent new things, she scribbled various diagrams and distinct charts in her notebooks. Even in Hollywood, she set up a mini-laboratory with the chemistry set. But, let us now see Lamarr's frequency hopping.

Frequency hopping, the system which has become associated with the actress and the composer, is a fairly straightforward process, although, in the years preceding and during World War II, its finer points eluded the scientists of the day [2]. Simply put, the frequency hopping procedure is comprised of sending a series of signals from a transmitter to a receiver in a manner that cannot be intercepted thereby allowing for a torpedo to be dropped remotely. Not only does it seem salient that the information pass from a transmitter to a receiver, but it is also essential that the message not be rendered such that it can be jammed easily by a third party (see, for instance, [2]).

In the early years of the war, however, she was having difficulty refining the details of frequency hopping, and precisely due to this fact she needed the help of George Antheil. Even though Antheil was famous for his composition skills, it was through his research on endocrinology that he met Hedy Lamarr, described as the most beautiful woman on earth (see [2]).

Antheil's art background (or music background, to be more precise) suggests that he contributed to the invention of frequency-hopping in terms of inserting the detail from his own music playing practice. Let us continue to suppose that Antheil assumed that swift changes in radio frequencies may be coordinated in the same manner as he coordinated pianos for his work of art. He brought the evidence in favour of his assumption that promptly alternating frequencies ought not to be jammed.

According to [2], Lamarr and Antheil would spend many hours in Hedy Lamarr's villa utilising the old matches and a silver matchbox, which they would place out on her carpet, whilst pondering over the idea how they would develop Hedy Lamarr's initial concept of frequency hopping realisation. For one thing, a whole lot of ideas emerged, one of them being putting a paper roll within the transmitter and the other paper roll within the receiver.

On our assumptions, from the available public records and the pertinent literature, each roll would be perforated in such a manner as to contain a randomly occurring pattern. A consequence of their approach just outlined was that the transmission itself would be expected to switch from one channel to another channel in a secret sequence, which would be far too complex to be intercepted by a third party. Apparently, this approach may remedy, and, at the same time, eliminate any interception, however, both the transmitter and the given receiver ought to be perfectly synchronised by means of a meticulously prepared components, which would be expected to memorise the given sequence of the channels involved. This synchronisation appears to correlate rather closely with the player piano rolls in a work of art put forward by Antheil.

One ingredient of their invention is apparently determined by Antheil's tools, namely, the piano. More specifically, the system was supposed to make use of eighty-eight frequencies, which is an equivalent number to the number of keys on a piano. Summarising, then, we may assume that this part of their invention was tightly connected to piano playing features.

Lamarr came up with the idea of a system that was intended to be utilised in order to activate radio frequencies. Her idea was rather attractive and appealing enough to motivate Antheil to devise a system of hopping between eighty-eight frequencies thereby providing the secrecy of any radio communication, and Lamarr got to the heart of frequency hopping since she was convinced that it could be applied to secure radio communications in such a way as to incapacitate and disable anyone since they would have to be able to follow the movement between frequencies so rapidly and repeatedly (see [3]).

Nevertheless, it should be pointed out the engineering part of the patent text was unselfishly supplied by Dr. MacKeown, a Professor of Electrical Engineering at the California Institute of Technology, who helped the frequency hopping inventors to polish the text of the patent No. 2,292,387. Finally, the patent was given the green light on 11th August 1942, and was given the title "Secret Communication System", and its creators were officially registered as Hedwig Kiesler Markey and George Antheil, respectively. Even though the gist of the patent specified that a high-altitude observation plane could steer the torpedo from above, the response of the navy was that the submitted proposal was not highly functional, and, additionally, the proposed invention was too cumbersome for utilisation within an average torpedo.

As I have already mentioned, in 1942, Lamarr and Antheil received U.S. Patent Number 2,292,387 for their invention, and formally, they may be credited with the invention of frequency hopping (see Figure 4). Furthermore, it has been argued so far that Lamarr's discovery of frequency hopping seems to have been a crucial founding element in the later development of Bluetooth and Wi-Fi technologies (see, for instance, [3]). However, according to another pertinent record (see [4]), Lamarr and Antheil submitted their joint patent on 10th June 1941, and, subsequently, the patent was granted on 11th August 1942, the text of which contained Lamarr's name represented as Hedy Kiesler Markey, which was actually her married name at the time of the patent submission (see [4]).

Broadly speaking, frequency hopping was not an entirely new concept. Allegedly, and according to some unreliable sources, Nikola Tesla alluded to frequency hopping in certain patents. A similar patent for a “secrecy communications system” was granted in 1920, with additional patents granted in 1939 and 1940 to two German engineers. And in the 1980s, evidence came to light that during World War II, the US Army Signal Corps worked on a communication system that used the spread spectrum concept as well.

Frequency hopping became later better known as spread spectrum technology, and the primary purpose, at least the one proposed by Lamarr and Antheil, was to enable launching of long-range missiles in such a manner as to prevent the third party from electronic jamming. It is though this joint endeavor that Hedy Lamarr realised that she had met the collaborator she desperately needed to develop her patent (see [1]).

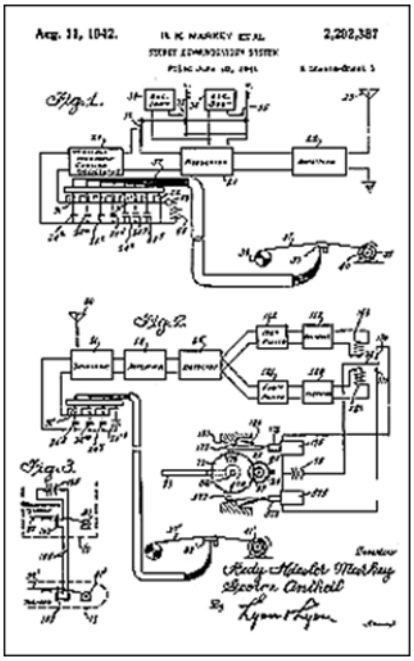


Figure 4: The photograph of the patent excerpt. There is no caption in the original document. The photograph was provided by the Courtesy of the American Physical Society - APS. APS News, June 2011 (Volume 20, Number 6).

Perhaps the most striking piece of information refers to the detail that Hedy Lamarr regarded her discovery of frequency hopping as a sort of her key for the gate of science, in the domain of which she may be finally recognised as a scientist. It was due to this that Hedy Lamarr was not ready to give up on her invention hope (see, for example, [3]). This was apparently determined by her contribution, which ought to be regarded as the basis for the plausible design focussed on a torpedo guidance system.

Strictly speaking, their joint endeavour might be broken into two parts. The first one was Lamarr’s contribution through the initial idea of frequency hopping, whilst the second one was Antheil’s practical experience with his composition, entitled *Ballet Mécanique*. The mentioned composition

ought to be regarded as a relevant ingredient encompassing the idea of devising a means of synchronising Lamarr's idea of rapidly changing radio frequencies (see [4]).

For the purpose of clarification, one ought to mention that their joint invention made use of a mechanism not quite equivalent to, but rather similar to piano player rolls aimed at synchronising the changes between the eighty-eight frequencies [4]. Notice, incidentally, that the mentioned number, i.e. eighty-eight, represents the standard number of piano keys. It has been suggested that the preliminary outline of their invention referred also to a high-altitude observation plane that would steer a radio-controlled torpedo from above (see, for instance, [4]).

The question that has been posed in the literature on the subject is the following one: "Did Hedy invent independently or simply borrow the "ideas" she had "retained … in basic form"?" [5]. The quoted source, however, highlights that "The misogynistic debate about whether or not Hedy's ideas were original or borrowed continues to this day" [5].

Let us see the relationship between Antheil and Lamarr. On our assumptions, it may be, then, that their relationship might have been influenced by the fact that both of them were native German speakers, both former members of the European artistic community, and these were sufficient reasons to put them together [5]. In an attempt to answer the question whether it is possible to establish the nature of their liaison and/or friendship, one ought to have recourse to the publicly available data mainly based on idle gossip, which seems to have been the necessary ingredient of the society, at least from the anthropological point of view (see, for instance, [6]). Backed by this idea, one cannot help but pay attention to the detail provided in the literature, according to which, Hedy Lamarr wrote her telephone number on George Antheil's windscreen using her lipstick [5].

Additional questions, based on assumptions and gossips, were posed in the literature. The two striking questions, according to the pertinent literature (see [5]), would be: 1. How did an actress and a composer go about inventing a remote controlled torpedo?, 2. What was original about their invention that allowed them to successfully patent it, as they eventually did? [5]. These are just some of the plausbile questions. Furthermore, these, and similar questions kept appearing, like the one referring to a problem Hedy Lamarr foresaw in connection with torpedo control by radio, namely, the problem of jamming. According to the literature, she never said how she had known that set frequency radio-control systems had been easily jammed (see, for example, [5]).

A consequence of the approach just outlined might lie in the explanation utilising the concept of serendipity, as well as thinking 'outside the box'. Summarising, then, one may assume the necessity of introducing the concept of 'happy thought', which may be explained in terms of the spontaneous conception – the one which has not been previously presented in the realm of invention.

The concept of serendipity, particularly its diachronic development, and its translatability problems, more specifically, certain difficulties in finding an appropriate translational equivalent, have been discussed in the pertinent literature on the subject so far (see, for example, [7], for a detailed discussion). It was noticed, incidentally, for example, that Claude Shannon and his student Irwin Jacobs had independently formulated Information Theory, at the same time [7].

It has been argued that more often than not the inventive process follows a whole lot of ideas and some thoughts, usually somehow interconnected, which are usually expected to be found separately, stranded, as it were, seemingly unrelated and not obviously connected (see [5]). The quoted reference takes into account the unconventional ways of thinking 'outside the box,' which would unavoidably lead to serendipitously establishing the connection between the superficially unrelated concepts thereby setting up the path for creating a brand new idea.

In what follows, I shall attempt to delineate the lines along which Hedy Lamarr's contribution may be handled, primarily basing my claims on descriptive accounts at hand. The point that needs to be

further explained is concerned with outlining Lamarr's original idea. We have already seen that in case when a radio transmitter and a receiver are synchronised to change their tuning simultaneously, hopping together randomly from frequency to frequency, then the radio signal passing between them cannot be jammed (see, for instance, [5]). With this clarification, it is evident why Hedy called this idea "hopping of frequencies".

Let us continue to suppose that she originally employed the German compound word *Frequenzsprungverfahren*, which she consistently utilised in developing her ideas, and her patent, for that matter, and selected the translational equivalent "frequency-hopping process", or, more precisely, the term "frequency hopping". Being aware of the fact that mental part cannot be patented, their idea required a physical embodiment, or to borrow the expression, Lamarr and Antheil needed to reduce their idea and invention to practice. Nevertheless, both Antheil and Lamarr deliberately avoided clearly specifying the mechanism for simultaneous change of tuning in their patent text (see [8], for a detailed account). Reducing to practice may remedy and, at the same time, eliminate any doubts about the implementation of a patent.

According to the pertinent literature (see, for instance, [5]), reduction to practice, was to be regarded as fulfilling the U.S. Patent Office formal requirements. Naturally, an inventress, who is legally speaking, a claimant is obliged to provide a miniature working model of her invention in order to demonstrate the functionality and the plausible operation of her invention. Not surprisingly, since one assumes that even all formal systems cannot be treated on a par (see, for instance, [9]), but rather be utilised as guides, this process of selection may be trivial, but then it should be readily demonstrable.

Even though the joint effort of Lamarr and Antheil was not officially adopted, the patent was utilised before its expiration date, but without specifying the names of the inventress and the inventor (see [2]). Apart from observing that the system was commonly called 'frequency-hopping', certain authors highlighted that its official name was 'Code Division Multiple Access', or CDMA, to abbreviate it and thus make it shorter (see, for example, [2]). It should be noted that the CDMA was installed on ships in 1962, after the Lamarr-Antheil patent had expired. It seems to me that in this manner, their genuine influence has been neutralised to a certain extent.

In contrast to this attitude towards Lamarr-Antheil patent, subsequent patents, taking their place in frequency-changing, refer to the Lamarr-Antheil patent as the foundation for the given field (see [2]). The last item to be discussed here is that of the legacy of Hedy Lamarr in the domain of Frequency Hopping.

Despite the fact that the Lamarr-Antheil patent was not widely acknowledged at that particular period of the history of science and history of invention, and that sometimes even other patents and intellectual contributions of this sort did not clearly refer to the Lamar-Antheil patent, Hedy Lamarr remained the most glamorous name associated with Code Division Multiple Access and Frequency Hopping, for that matter. As an additional contribution to this claim, one may take into account Hedy Lamarr's legacy which has been expressed as the explicit and tangible textual evidence of the patent number 2,292,387.

But, before we continue with the linguistic analysis of the patent text, one ought to consider the engineering aspects of 'spread spectrum' and 'frequency hopping' in the section that follows.

4 From Simple Structures to Complex Ideas: Delving into Spread Spectrum and Frequency Hopping

Broadly speaking, the invention of Hedy Lamarr seems to have been represented as the underappreciated intellectual contribution even though Lamarr's frequency-hopping system is integral to modern GPS, secure Wi-Fi, and military satellites (see [10]). Nevertheless, it was Lamarr's collaboration with George Antheil during World War II that solidified her legacy as an inventress.

Their formal patent submission was not well-accepted by the Navy. This piece of information suffices to account for the fact that discouraged by the Navy's attitude, Lamarr and Antheil did not pursue their invention further (see [11]). Although, not accepted by the National Inventors Council, her invention was applied in contemporary Global Positioning System (GPS), secure Wi-Fi, Bluetooth, as well as military satellite technologies [10]. The inventress Lamarr is also credited with developing a scrambler that secures communications, or more precisely, she played a role in the technology, according to the pertinent literature (see [12]).

From the title of this phenomenon, i.e. spread spectrum, it follows that the idea of the intended transmission has to utilise a far wider bandwidth in the electromagnetic spectrum than the bandwidth imposed by the original information signal. The term 'spread spectrum' was coined back in the 1960s by Madison Nicholson and John Raney, two engineers who, according to [12], pioneered in developing this system.

The working definition of the term 'frequency-hopping spread spectrum', or briefly, FHSS, might be the following one: FHSS is said to represent a method of transmitting radio signals in such a manner that it swiftly alternates the carrier frequency among diverse divergent frequencies occupying a large spectral band. Of course, changes are managed and controlled by a code known to both transmitter and receiver.

This tentative and working definition might serve as a starting point in an attempt to re-evaluate some former and current approaches to frequency hopping phenomena in the literature on the subject. However, since this part is mainly descriptive in orientation, we shall neither evaluate nor arbitrate between the assertions cited from the pertinent literature on the subject.

Let us now see some aspects of spread-spectrum which have been utilised in determining the origins of spread-spectrum communications. In the literature describing these origins, the first assertion focusses on the appearance of the concept of spread-spectrum. More specifically, it has been claimed in the literature that the concept of spread-spectrum (SS) has come into view from its confidentiality and clandestineness by means of the path generated through the Global Positioning System (GPS) and the Joint Tactical Information Distribution System (JTIDS), even though, it seems that the history of this robust communication technique remains largely fuzzy to communication engineering experts (see [13]).

The descriptive strength of this historical approach lies in its pointing out the necessity of an interpretation of certain concepts relevant for this topic. The basic signal characteristics, which pertain to modern spread-spectrum systems, are delineated and further specified in the literature on the subject. According to the quoted reference, [13], these basic signal characteristics establish the nature of the carrier, which ought to be an unpredictable, or pseudorandom, wide-band signal. Furthermore, the next feature refers to the bandwidth of the carrier, and this bandwidth is supposed to be much wider than the data modulation bandwidth. Finally, the third property is concerned with reception. A general convention within this model is that reception is to be accomplished by means of cross-correlation of the received wide-band signal with a synchronously generated replica of the wide-band carrier (see [13]).

Another concept brought to one's attention refers to frequency hopping systems. In the literature, frequency hopping (FH) systems achieve carrier spreading by driving a frequency synthesiser with a pseudorandom sequence of numbers spanning the range of the synthesiser [13]. Moreover, it has been claimed, in the quoted literature, that data may be usually frequency-shift-keyed (FSK) onto the spread carrier but solely in the authentic and flawless form type of this system.

The next approach to be discussed is concerned with further notes on spread-spectrum origins. Certain authors thoroughly describe the period shortly before Pearl Harbor, particularly focussing on the Lamarr-Antheil Frequency-Hopping invention (see [14]). The foreground assumption is that Hedy Lamarr was an inventress of the first frequency-hopping spread-spectrum technique explicitly conceived for anti-jamming communications. Furthermore, the reference [14] stresses that in mid-1941 an application for the Frequency Hopping patent was filed by Hedy K. Markey and George Antheil, without their awareness of the existence of the method of maintaining secrecy in the transmission of wireless telegraphic messages, which was proposed and filed by Broertjes in Germany on 11th October, 1929, and then in the U.S.A. on 2nd August, 1932, respectively.

According to [14] and [15], Hedy Lamarr and George Antheil created large diagrams whilst stretched out on Lamarr's carpeted floor. In particular, it should be emphasised that Lamarr and Antheil concentrated on these precisely created drawings, and afterwards they came up with the idea of a secure, viable and feasible concept of Frequency Hopping Spread-Spectrum. It was also underlined that the design of this specific system utilised the composer's know-how, particularly whilst the two of them were planning to synchronise the radio transmission and reception frequencies by means of identically crypto-code slotted, paper music rolls like those used in player piano audio-frequency mechanisms (see [14] and [15]). According to the layout of their patent, the Frequency Hopping of eighty-eight radio frequencies might be readily accommodated within this pattern. For one thing, Frequency Hopping secretiveness features of the Lamarr-Antheil invention were augmented and enhanced by the introduction of short-pulse transmission aimed at providing low detectability (see [14] and [15]).

In this brief chronological survey, I have noticed that even the state-of-the-art literature proposing new guidelines, concepts and design techniques that can be used for future ultra-low power wireless radio links makes use of the concepts of Frequency Hopping, among other things (see, for example, [16]). According to these authors radio power consumption still seems to represent impediment and obstacle incapacitating the extensive adoption of this technology.

What [16] suggests refers to dissimilar paths which ought to be explored in order to minimise the radio consumption. However, the first and foremost difficulty pertaining to the proposed solutions lies in sort of reduced wireless link robustness. With this clarification, a similar view is then expressed and employed whilst considering some aspects of striking architectures and synthesisers for ultra-low power fast Frequency-Hopping WSN radios [16]. So, one can conclude that even the advanced models and systems employ the legacy of Hedy Lamarr's Frequency Hopping.

Briefly, current approaches to the phenomenon under consideration could be better grasped if we look at the historical perspective of frequency hopping spread spectrum. Let us see the definition, found in the literature, according to which, frequency hopping spread spectrum is a technique that many ultra low power (ULP) radio protocols use to overcome the problems of interference in the crowded 2.4 GHz band [17]. Up to now, we have seen the concise definition of the process, and let us now see how this technique partakes in the process by sub-dividing the 2.4 GHz band, this band being extended from 2.4 to 2.48 GHz into channels of varying frequency [17]. Subsequently, the transmitter broadcasts on a particular channel and if the receiver detects interference, both the transmitter and the receiver jump to a different (and hopefully clearer) frequency. These might be said to be conditions that must obtain for the transmitter and the receiver to be able to carry out the

given frequency jumping. Therefore, it is hardly surprising that FHSS is considered to be simple, elegant, and effective, according to the literature (see [17]).

Following the chronological account, proposed by [17], in a nutshell, the inventress Lamarr, together with her co-inventor George Antheil came up with a system for radio control of torpedoes. The quoted reference stated that the idea itself was not new. However, Lamarr's concept of Frequency Hopping aimed at preventing the intended target from jamming the controller's transmissions was quite original (see, for instance, [17]).

Similarly to the previous accounts, this one also points out that the system used eighty-eight different carrier frequencies, which is equivalent to the number of keys on a piano. This technique was focussed on synchronising the frequency hopping between the transmitter, which was to be located in a plane flying above the torpedo and the weapon itself (see [17]). The quoted source adds that the Lamarr and Antheil's patent obtained the mysterious and puzzling title – "Secret Communication System".

As regards their contribution, diverse contemporary patents in FHSS technology refer to the Lamarr-Antheil patent document as the basis of the field. It has also been claimed that today's Bluetooth low energy and proprietary protocols owe much to the amazing intellect of this beautiful actress and gorgeous inventress (see, for example, [17]). Let us see how some of the relevant terms are defined in some current accounts.

Let us first go to the concept of 'spreading'. More specifically, spreading is determined as a sort of operation of enlarging or spreading the spectrum. In addition to this, it is pointed out that several spreading codes can be used for spectrum spreading (see, for instance, [18]). Historically speaking, spread spectrum systems have been developed since the mid-1950s [18]. Furthermore, spread spectrum systems were initially utilised for anti-jamming tactical communications, guidance systems, as well as experimental anti-multipath systems in the military context and domain (see [18]).

To characterise a spread spectrum system, one has to observe the literature on the subject. Apparently, a spread spectrum system is defined as such a system in which the transmitted signal is spread over a wide frequency band. And this band is much wider than in the case of the minimum bandwidth, which is required to transmit the data being sent. It is highlighted in the literature that band spreading is accomplished by means of a code which is independent of the data [18]. It is necessary to impose an interpretation on a reception, which is, in this case, and according to the described scenario, synchronised to the code, and subsequently, this reception is used to despread and recover the data at the receiver (see [18]). It is widely accepted that spreading the spectrum can be applied in diverse contexts and domains, as is the case with anti-jamming, interference rejection, low probability of intercept, multiple access, multipath reception, diversity reception, high resolution ranging, and accurate universal timing, to name just a few (for a fuller account, see [18]). A general convention regarding the spread spectrum concepts for multiple access refers to two paramount kinds, the first one being direct sequence code division multiple access, i.e. DS-CDMA, the second one being frequency hopping code division multiple access, i.e. FH-CDMA (see, for instance, [18]).

We have seen so far historical and engineering accounts of the invention under consideration. In a nutshell, in 1941, Hedy Lamarr and George Antheil devised a jam-resistant guidance system for torpedoes, the aim of which was to control the transmission frequencies by means of slotted paper rolls resembling the rolls used in player pianos (see [19]). Additionally, according to the descriptive accounts, certain spread-spectrum ideas were used in World War II, predominantly in the context of radars. It is in this context that synchronisation of the pseudorandom sequences between transmitter and receiver does not represent a problem (see, for example, [19]).

By stressing the common rule of thumb for assessing the efficiency of a modulation scheme, the approach of [20] is not unlike that of the other literature on the subject. More specifically, this modulation scheme efficiency aims at examining how tightly it concentrates the energy of the given signal for a given rate of information. Spread-spectrum modulation techniques are rather different from the compactness of the signal pertaining to the conventional wisdom. This is to say that spread-spectrum modulation signal is to spread the signal over a very wide bandwidth (see [20]).

A similar view of the consulted literature is expressed in [20], according to which communications signals may be increased to a great extent in terms of their bandwidth, or more precisely, by factors of 10 to 10,000. This is obtained by combining the given signals with binary sequences making use of several different techniques. Consequently, the result of this spreading is said to have at least two beneficial effects. The former refers to the signal energy dilution, whilst the latter obtains for the receiver, which may reject strong undesired signals, even the signals of greater strength than the desired spread-spectrum signal power density (see [20], for a detailed account).

The first effect, therefore, may be said to attenuate the amount of power density present at any point within the spread signal, since this signal seems to be very weak. Additionally, the signal dilution amount depends on several factors such as transmitting power, distance from the transmitter and the width of the spread signal. It is a descriptive fact that, on the one hand, the dilution may result in the signal being below the noise floor of a conventional and commonly expected receiver, and consequently be rendered invisible to the receiver, whilst, on the other hand, it can be received with a spread spectrum receiver, according to the literature (see [20]).

What this assertion from the quoted reference suggests is that this occurs mainly due to the fact that the desired receiver owns a spreading sequence copy, which is utilised to despread the signal. An important property that ought to be mentioned refers to non-spread signals that are in this case suppressed in the course of processing. The consulted source agrees with the other consulted data in terms of the validity and effectiveness pertaining to the interference-rejection property of spread spectrum, which has rendered it a popular military anti-jamming technique (see [20], for a detailed account). But, let us now concentrate on Frequency Hopping, since this phenomenon is in the focus of the investigation (and this paper, for that matter).

According to a descriptively adequate account, Frequency Hopping, sometimes abbreviated as FH, represents a form of spreading in which the center frequency of a conventional carrier is altered many times a second in accordance with a pseudo-random list of channels (see [20] for the explanation). Another important concept that has been introduced in the literature on the subject refers to the ‘dwell time’, which is defined as the amount of time the signal spends on any single channel. An important property of the dwell time is its duration. Namely, the dwell time has to be extremely short, commonly implying less than 10 milliseconds. Only in this case can it avoid interference to a conventional user and from conventional users (see [20] for a brief overview).

Elaborating on spectrum of spread spectrum, the consulted literature (for instance, [20]) demonstrates how each spectrum type of spread spectrum signal depends on several factors, such as the speed at which the spreading code is clocked. And then, each spectrum type of spread spectrum signal is attested by the type of the utilised spreading code, and it depends on whether frequency hopping or direct sequence is being used. In addition to this, the modulation bandwidth and the method of modulation are salient ingredients to which due attention should be given.

Whilst consulting the pertinent literature on the subject, we are frequently made aware of what has been accomplished in the domain of multi-carrier and spread spectrum communications, and one might conclude that this particular field of multi-carrier and spread spectrum communications has became a far-reaching investigation field and an outstanding research topic which calls for and results in an increasing number of diverse research activities (see [21] for a detailed discussion).

It has been also mentioned that new standardisation activities in the framework of beyond 3G concepts have been initiated, in addition to deep system analysis of various multiple access schemes. Finally, multi-carrier transmission might be considered to be a potential candidate to illustrate and underscore the requirements of the next generation system, according to the literature (see [21]). On the grounds of additional spreading, it has been shown (see, for instance, [22]) that multicarrier spread spectrum (i.e. MC-SS) may make available frequency diversity by means of additional spreading in order to overcome severely faded sub-channels.

On the grounds of certain features Frequency Hopping seems to be susceptible to specific application in certain domains. The last approach or more precisely, Frequency Hopping application, to be mentioned in this paper is Frequency Hopping in GSM. Rather than consider which descriptive account correctly captures the gist of Frequency Hopping and the role of Frequency Hopping in some aspects of engineering, as they all seem to highlight one important aspect of the overall Frequency Hopping picture, in the remainder of this part of the paper I shall consider the possibility of yet another case of Frequency Hopping application, confining my descriptive account to the proposal that the radio interface of GSM offers the slow frequency hopping functionality, according to the literature (see [23]).

This brings us to the question of the Frequency Hopping treatment in the literature dealing with its actual application in certain specific domains. Rather than describe the state of affairs within these domains, it is merely asserted that frequency hopping falls into the category of techniques that limits the influence from interference. At this point, frequency hopping is based on a relatively straightforward idea that every mobile station transmits its TDMA frames according to a sequence of frequencies specified by the frequency hopping algorithm [23].

Strictly speaking, a mobile station transmits on a fixed frequency during one timeslot and then, subsequently, jumps to another frequency previous to the next TDMA frame, the uplink and downlink frequencies being always duplex frequencies. Even though there are probably a whole lot of cases that do not easily lend themselves to such a clear-cut division, in the context of GSM at least two different modes of hopping are specified, and are illustrated by cyclic hopping and pseudo random hopping, according to the literature (see, for instance, [23]).

It seems to me that the actual application of spread spectrum shows to be propitious, as is the case shown in diverse case studies, some of which focus on spread spectrum communication link in spatial scenario with jammer and eavesdropper (see, for example, [24]). Given the pervasiveness of jamming and eavesdropping the question might be posed concerning the techniques utilised for countermeasures.

The answer provided in the literature (see [24]) seems to be fairly simple. Namely, the synchronisation of transmitters and receivers in space facilitates the space domain techniques utilisation for electronic countermeasures. Jamming and eavesdropping can be avoided by the proper use of space domain operators (see [24]), whilst the positioning of transmitters relies entirely on a considerably richer overall potential of the repertoire of space domain techniques.

To sum up, in a great many instances, Frequency Hopping is defined as the periodic changing of the carrier frequency of a transmitted signal (see, for example, [25]). It is further highlighted that the given time-varying characteristic may potentially supply a communication system with great strength against interference. In addition to this, it is pointed out that, aimed at suppressing interference a direct-sequence system relies on three ingredients: 1. spectral spreading, 2. spectral despreading, and 3. filtering, respectively (see [25] for a detailed discussion). The most prominent term within this framework is the notion of ‘avoidance’, which is mostly grouped under the common label of the fundamental mechanism of interference suppression in a frequency-hopping system. In other words, when the avoidance fails, it is only temporary because of the periodic

changing of the carrier frequency [25]. In the part that follows, we shall see some linguistic aspects of the text of the patent of Hedy Lamarr and George Antheil.

5 Some Linguistic Aspects of Frequency Hopping Patent

The patent, entitled “Secret Communication System” belongs to a subset of the set that pertains to formal languages, or, more specifically, formal registers. Even though this part of the paper does not aim at rectifying the persistent theoretical and methodological problems in dealing with discourse phenomena, as well as the clear distinction between the terms ‘discourse’, ‘text’ and ‘register’ some observations are, nevertheless, in order. More precisely, my discourse/text-driven investigation has been informed by the following references: [26]—[29], whilst the definitions of the register and style have been taken from the following sources: [30]—[36]. The part of my analysis concerned with Formal English, the language of legal documents, textual dimensions and textual variations has been informed by the following references: [37]—[40].

This part is motivated by the assumption provided by the pertinent linguistic literature, (see [39] for a detailed discussion), that the permanency of writing enables the dissection of texts, so that these texts can be further critically examined. Since this text type is a patent, it belongs to the language of legal documents, and it is argued that legal language covers quite wide scope of activities and sometimes becomes even blurred at the edges (see [38], for a detailed account of this assertion). Also, the language for the formal system (as is the case of Legal English) consists of a set of terms together with a set of formation rules and meaning postulates appropriate to them [9]. But let us see the actual text of the Lamarr-Antheil Patent.

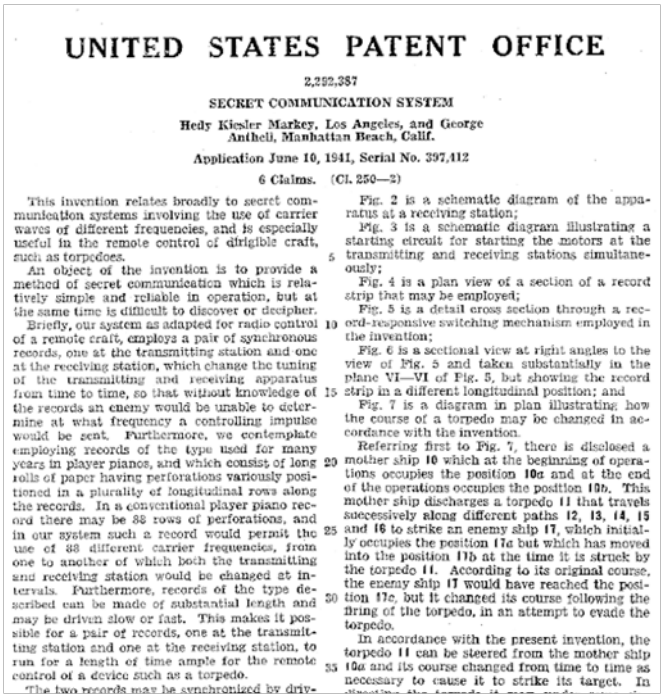
The patent is entitled “Secret Communication System”, and it contains the following initially placed formal elements: the serial number and the application date (see Figure 5). These listed items are said to be the salient formal elements of this document type, or, more precisely, a patent. Some discoursal and textual features of the patent would be comprised of the syntactic constructions, among other things. The text of the patent opens with the following items: “This invention relates broadly to secret communication systems involving the use of carrier waves of different frequencies…” [8]. This opening is typical of the text pertaining to legal English documents, since in the patent text, it immediately describes the relation of the invention to be exposed.

The second paragraph starts with the main statement of the patent, claiming that “An object of the invention is to provide a method of secret communication which is relatively simple and reliable in operation, but at the same time is difficult to discover or decipher.” [8]. As can be seen from these linguistic items, this part of the patent text provides an object of the invention itself and by introducing the linguistic item ‘a method of secret communication’ it connects it with the title of the patent. The authors of the patent utilise formal and technical lexical items, which is expected in this text type.

Another striking feature of legal texts, the patent not being an exception to the general rule, refers to explicit mentioning of concrete numbers of items employed in the patent. For example, the text claims that “In a conventional player piano record there may be 88 rows of perforations, and in our system such a record would permit the use of 88 different carrier frequencies, from one to another of which both the transmitting and receiving station would be changed at intervals.” [8].

The text makes use of the prepositions typically used in Legal English; such as ‘theoreof’ in the sentence “Other more specific objects and features of our invention will appear from the following detailed description of a particular embodiment thereof, as illustrated in the drawings, in which Fig.

1 is a schematic diagram of the apparatus at a transmitting station" [8]; and the preposition 'thereupon' in the following excerpt: "which thereupon modulates the particular carrier wave" [8]; the preposition 'whereupon' in the following excerpt: "identical with the solenoid 175 are released, whereupon the pawl 177 and plunger 176 are retracted into neutral position by the spring 180" [8]. In addition to this, diverse constructions pertaining to the technical register and formal styles are also used in the patent text, some of which are: "Referring first to Fig. 7", "In accordance with the present invention, the torpedo II can be steered from the mother ship", "Under the particular circumstances of", "In accordance with our invention, we employ variable frequency radio transmitters and receivers for the remote control" (see [8]). Impersonal constructions contributing to impartial and unbiased process description are also employed in the text of the patent, for example, "Actuation of the key L closes main contacts", "Furthermore the frequency changes can be purely arbitrary, without any periodic recurrence that would render it easy for an enemy to anticipate the frequency at any particular instant." [8]. The patent text is also freighted with the passive voice, for example "and a signal selector that may be tuned to any one of four different frequencies by connecting thereto different condensers", "When the condenser 24'd is connected to the selector", "the transmitter and receiver are both tuned to the same frequency", "when the transmitting apparatus is tuned to frequencies that are not receivable at the receiving station", "the signal is amplified in an amplifier and delivered to a detector", "If a received signal was produced by actuation of the key L".



UNITED STATES PATENT OFFICE

2,292,387

SECRET COMMUNICATION SYSTEM

Hedy Kiesler Markey, Los Angeles, and George Antheil, Manhattan Beach, Calif.

Application June 10, 1941, Serial No. 397,412

6 Claims. (Cl. 250—2)

This invention relates broadly to secret communication systems involving the use of carrier waves of different frequencies, and is especially useful in the remote control of dirigible craft, such as torpedoes.

An object of the invention is to provide a method of secret communication which is relatively simple and reliable in operation, but at the same time is difficult to discover or decipher.

Briefly, our system as adapted for radio control of a remote craft, employs a pair of synchronous records, one at the transmitting station and one at the receiving station, which change the tuning of the transmitting and receiving apparatus from time to time, so that without knowledge of the records an enemy would be unable to determine at what frequency a controlling impulse would be sent. Furthermore, we contemplate employing records of the type used for many years in player pianos, and which consist of long rolls of paper having perforations variously positioned in a plurality of longitudinal rows along the records. In a conventional player piano record there may be 88 rows of perforations, and in our system such a record would permit the use of 88 different carrier frequencies, from one to another of which both the transmitting and receiving station would be changed at intervals. Furthermore, records of the type described can be made of substantial length and may be driven slow or fast. This makes it possible for a pair of records, one at the transmitting station and one at the receiving station, to run for a length of time ample for the remote control of a device such as a torpedo.

Fig. 2 is a schematic diagram of the apparatus at a receiving station;

Fig. 3 is a schematic diagram illustrating a starting circuit for starting the motors at the transmitting and receiving stations simultaneously;

Fig. 4 is a plan view of a section of a record strip that may be employed;

Fig. 5 is a detail cross section through a record-responsive switching mechanism employed in the invention;

Fig. 6 is a sectional view at right angles to the view of Fig. 5 and taken substantially in the plane VI—VI of Fig. 5, but showing the record strip in a different longitudinal position; and

Fig. 7 is a diagram in plan illustrating how the course of a torpedo may be changed in accordance with the invention.

Referring first to Fig. 7, there is disclosed a mother ship 10 which at the beginning of operations occupies the position 10a and at the end of the operations occupies the position 10b. This mother ship discharges a torpedo 11 that travels successively along different paths 12, 13, 14, 15 and 16 to strike an enemy ship 17, which initially occupies the position 17a but which has moved into the position 17b at the time it is struck by the torpedo 11. According to its original course, the enemy ship 17 would have reached the position 17c, but it changed its course following the firing of the torpedo, in an attempt to evade the torpedo.

In accordance with the present invention, the torpedo 11 can be steered from the mother ship 10a and its course changed from time to time as necessary to cause it to strike its target. In

Figure 5: The photograph of the patent text. The original caption contains the following text: "Patent filed by Hedy Lamarr and George Antheil for a "Secret Communication System," application June 10, 1941." The photograph was provided by the courtesy of the Jewish Women's Archive – JWA.

What all these excerpts have in common pertains to their syntactic, semantic and pragmatic aspects. Formal English is expected to be typically found in the written language material, i.e. certain written documents, and is intended for circulation among a somewhat restricted group (see [37]). According to the literature, the vocabulary pertaining to Formal English contains many specialised words (see [37]). Whoever composes a legal document of any sort ought to make an effort to ensure

that such a document states exactly what the legal document writer wants to state, and simultaneously, this document should give no opportunity for misinterpretation (for instance, see [38]).

As regards the clause structure, and the sentence structure, for that matter, there is a general tendency to length and complexity in the patent text, which is in line with the observations proposed in the literature (see, for example, [38]). Let us see the excerpts from the text of the patent illustrating this complexity. For instance, the following excerpts: “Referring first to Fig. 7, there is disclosed a mother ship 10 which at the beginning of operations occupies the position 10a and at the end of the operations occupies the position 10b. This mother ship discharges a torpedo 11 that travels successively along different paths 12, 13, 14, 15 and 18 to strike an enemy ship 17, which initially- occupies the position 17a but which has moved into the position 17b at the time”; “In accordance with our invention, we employ variable frequency radio transmitters and receivers for the remote control, and change the frequency at intervals by synchronous records at the two stations.”; “In accordance with the present invention, the torpedo 11 can be steered from the mother ship 10a and its course changed from time to time as necessary to cause it to strike its target. In directing the torpedo it may, under some circumstances, be observed directly from the mother ship 10, or its course may be followed by an observer in an airplane 18 who communicates his findings to the mother ship 10a.” [8].

In patent drafting there are some salient ingredients that ought to be included, some of which have been expected to appear in the patent text. Strictly speaking, Hedy Lamarr’s patent contains these formal elements. Let us further examine some formal elements. More specifically, the analysed patent text contains the title of the invention (“Secret Communication System”) accompanied by the number 2,292,387 and the names and surnames of the submitting parties (Hedy Kiesler Markey, George Antheil) accompanied by their whereabouts (Los Angeles and Manhattan Beach, California, respectively). Subsequently, the patent contains the date of submission (10th June 1941), and the serial number 397,412, as well as the precise number of claims (“6 Claims”).

The patent contains the statement outlining an object of the invention, contained in the following patent excerpt: “An object of the invention is to provide a method of secret communication which is relatively simple and reliable in operation, but at the same time is difficult to discover or decipher.” In addition to this, the patent incorporates a summary of the Secret Communication System and a concise description of the drawings employed in the patent document. In the continuation, the submitting parties, Hedy Kiesler Markey and George Antheil, provide a detailed description of the submitted patent.

Another striking linguistic feature that can be detected is a sort of tentativisation. Namely, it is interesting to note that the patent text contains certain lexical items and discourse devices, which might be interpreted as hedges to a certain extent. Next, the authors of the patent point to the aspects that remain underexplored, when they state that “Apparatus as described in claim 1, including means at the transmitting station for transmitting radio signals of different frequencies to which said radio receiver tuning means are not tunable, and means coordinated with the recordings on said first strip for indicating at the transmitting station when the transmitting apparatus is tuned to frequencies that are not receivable at the receiving station”, which might be linguistically described as a sort of conclusion of this discourse type.

Relevant to the question of linguistic analysis my direction goes in favour of the structural treatment whilst observing the patent text. Unfortunately, the other perhaps more attractive approaches, as well as the models of analysis no less interesting, could not be taken up in this paper. Therefore, plausible ways of analysis merit further investigation.

Suffice it to say that the employed structural analysis has treated the data in a direct and conventional way, as it has been shown. Some other, perhaps more appealing, approaches, models and methods may be applied in future research. However, it is felt that this analysis may also serve as a basis for further elaboration.

6 Concluding Remarks

The facts which have so far been described in this paper, with the minimum of argumentation accompanying them or entailed by their selection, and with primarily descriptive orientation, are intended to enable the reader to try to form a well-founded judgement of the nature of frequency hopping and, ultimately, Hedy Lamarr's contribution and her invention. After a lengthy process, Code Division Multiple Access (CDMA) was adopted as the standard and Hedy Lamarr and George Antheil's invention became the base of all modern telephone technology (or spread-spectrum technology). Another important aspect of Frequency-Hopping technology is that is seems crucial to Global System for Mobile (GSM) telephones due to the fact that it allows privacy for callers. Strictly speaking, Hedy Lamarr was the most glamorous name associated with this work, and her legacy is contained in the concrete evidence of the patent number 2,292,387.

In this paper, I have re-examined Frequency Hopping primarily from the historical perspective and based on descriptive accounts, which take into consideration its actual application.

To this purpose, I have analysed certain linguistic aspects of the text of the actual patent, submitted by Hedy Lamarr and George Antheil. The neat examples of the illustrative excerpts, cited in that part of the paper, are relatively straightforward cases of typical patent document type discourse.

This paper aims at promoting an interest in the study of Hedy Lamarr as an inventress of Frequency Hopping as there is ample evidence that she contributed to a well-defined field of investigation within and across electrical engineering, generally, and telecommunications, more specifically. At the same time, this paper may also contribute to a better understanding of heterogeneous aspects of frequency hopping and its role and implications in contemporary theories and applications.

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