# On the Development of Early Vocoders

Rüdiger Hoffmann

Technische Universität Dresden, Institut für Akustik und Sprachkommunikation,
Professur für Systemtheorie und Sprachtechnologie, 01062 Dresden, Germany

***Abstract* — The historic acoustic-phonetic collection (HAPS) of the Dresden University of Technology [47] preserves historic material from more than 100 years of experimental phonetics in Germany and more than 50 years of speech technology in Dresden. The latter begun with the development of a channel vocoder in the 1950-th which was the starting point for continuous investigations in speech analysis and synthesis. More general, the development of early vocoders had a large impact on speech research in other places also, starting with Dudley's vocoder in the 1930-th. Therefore, this paper will give a survey of the development of early vocoders including some examples for the impacts which they had. Although this study cannot be complete, it gives an impression of pathbreaking work.**

***Index Terms* — Communication systems, history, music, speech coding, speech synthesis, vocoders.**

## I. Introduction

### *A. The Origin of the Vocoder*

The development of radio engineering and communication technology in the 20th century posed a number of new questions about the physical nature of the speech signal. Speech, hitherto a topic investigated by phoneticians and linguists, started to be a research object of engineers and physicists. They investigated numerous psychoacoustic effects along with the spectral structure of speech. The textbook *Speech and Hearing* from 1929 [1] by the physician Harvey Fletcher (1884-1981) is a milestone in this development.

The speech signal was recognized to need a bandwidth of approx. 3.000 Hz for a sufficient transmission quality, and the frequency range from 300 to 3.400 Hz was standardized as the telephone bandwidth. This bandwidth was too large for a number of technical systems especially in the field of cable transmission. Thus, different ideas arose to utilize the physical properties of the speech signal for a less redundant representation by suited parameters which, in turn, require less transmission capacity. This idea is characterized by the scheme of Figure 1 and is known as *voice coding*. Homer Dudley (1896-1980) coined the term *vocoder* for the combination of transmitter and receiver in Figure 1. He developed the first vocoder where the parameterization of the speech signal was performed by measuring the signal power in a number of adjacent frequency bands (channels). The information whether the signal was voiced or unvoiced and, if voiced, the fundamental frequency (for the prosody or "speech melody") must be transferred as additional parameters.

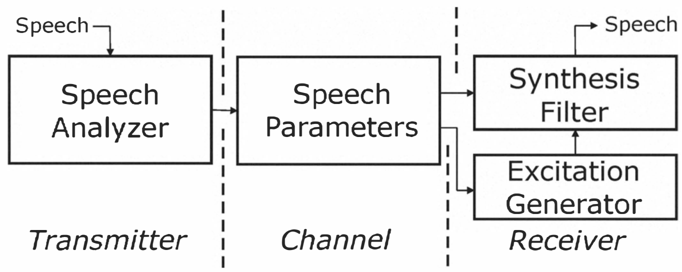


Fig. 1. Basic principle of a vocoder-like system for speech compression and transmission.

This principle of the so-called channel vocoder (which will be illustrated below in Figure 3) was supplemented later on by approaches which used different methods of parameterization (cf. [2] and especially Table 4.2 in [4, p. 74]). Therefore, the later literature offers terms like *formant vocoder*, *correlation vocoder*, *LPC vocoder* and some other.

### *B. Aim and Restrictions of this Paper*

This paper is a historic one. The vocoder, however, is not at all history. Its principle began to play an important role with the availability of semiconductor circuits and, later, digital signal processing. This role is still ongoing in speech technology, communication engineering, and electronic music. Therefore we restrict ourselves to the time before the beginning of that era, when the experimental vocoder prototypes were still large and complicated analog devices.

The channel vocoder, which was developed in the 1930-th by H. Dudley at the Bell Labs, is the famous and pioneering prototype. It is less known that there were similar patents and publications in Germany at the same time [18, 19, 23], followed by a number of vocoder developments in Europe. This paper is concentrating especially on the history of two vocoders in the former two parts of Germany. The older one was a development of Siemens, and a revised version of it is now exhibited in the Deutsches Museum Munich. The other was constructed at the Dresden University of Technology in the 1950-th. There are no more physical remnants of the Dresden vocoder, but we have a good documentation as well as a number of sound recordings in the historic acoustic-phonetic collection (HAPS) of the TU Dresden.

Other vocoder developments in Europe (including the former Soviet Union [17]) will not be considered here, except from the two cases (UK and Ericsson) which have influenced the development in Germany. It is interesting to study the

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influence of the vocoders on the development of telecommunications and related disciplines. Clearly, a real application in telecommunications was not very useful before digital signal processing became applicable. There were, however, large impacts of the early vocoders on the development of speech technology and related fields. They were basing on the fact that the analyzing and synthesizing subsystems of the vocoders could be used as experimental devices in basic research.

## II. The Famous Bell Vocoder

The development at Bell Labs is well known [5, 6] and will be summarized very shortly here. According to [2, 3], H. Dudley sketched the idea to transfer speech by means of the spectral information in his laboratory-notebook in October, 1928. The motivation came from the installation of a new transatlantic telegraph cable with a bandwidth of 100 Hz which was much for that time but too low to transfer unprocessed speech.

The development of the device is documented in several patents and papers. A first demonstration took place in 1936. The original patent [7] from 1937 (applied 1936) describes the idea in detail. The term *vocoder* appears firstly in the publications of the years 1939/40 [9–12]. The receiver part served as the base of a manually controlled speech synthesis system, the *voder* [13] which means *vo*ice *de*monstrato*r*. This system was one of the main attractions of the World Fairs in New York and San Francisco 1939/40. Its description [14] includes a number of photographs which demonstrate how the generators and the ten filter channels of the device were controlled by an operator.

An application of the Bell vocoder was found during World War II for secure speech transmission. The history of the so-called *Project X* which included the vocoder is described in [6, pp. 296-317]. The special contributions of H. Dudley can be extracted from his patents [15, 16] which were published after the end of the secrecy of the project. It is reported that the vocoder was "used to scramble speech signals in the secret telephone link between Churchill and Roosevelt" [3, p. 35].

From the engineering point of view, the number and the arrangement of the filter channels of the vocoder is an important question. Dudley found that ten channels should be sufficient for subdividing the speech band with satisfying speech comprehension. Interestingly, the arrangements of the channels in the patents of the vocoder [7] and the voder [13] are *not* restricted to the telephone bandwidth of approx. 3,000 Hz. Dudley explains the selection of the bandwidths mainly with the importance of the respective bands for the articulation. This leads to a non-linear subdivision of the frequency scale which is illustrated in Figure 2. In contrast, the security application of the vocoder used telephone bandwidth with a linear subdivision of the speech band in ten channels of 300 Hz (labeled as Dudley III in Figure 2) [6, p. 300].

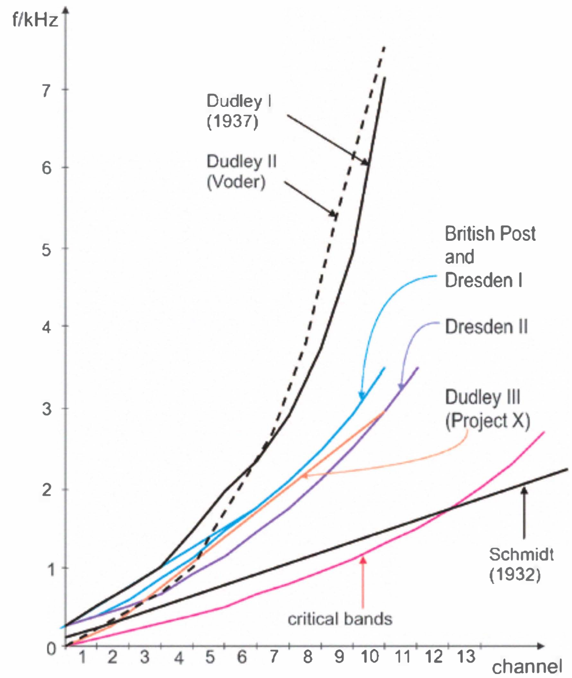


Fig. 2. Comparison of the arrangements of the frequency bands of the different historic vocoders, including the critical bands defining the mel or Bark scales in psychoacoustics.

## III. The Development in Europe

### *A. The Early Patents of K. O. Schmidt*

The discussion on the effective utilization of the available bandwidth in communication systems has a long history which is documented in an increasing number of patents in the 20th century. The idea to transmit speech via a number of adjacent filter channels was firstly patented by the German engineer K. O. Schmidt in 1932 [18]. The invention differs from the later vocoder only in that respect, that the fundamental frequency of the original signal was *not* transmitted, thus the speech melody could not reproduced at the receiver site. The inventor claimed that this feature could be omitted without degrading the speech comprehensibility. The proposed linear subdivision of the frequency range in 20 channels is included in Figure 2.

A number of years later, K. O. Schmidt added in a supplementary patent from 1939 [19] the detection and the transfer of the fundamental frequency to his system. The complete block diagram is shown in Figure 3. We do not know, unfortunately, in what extent the ideas of K. O. Schmidt have been implemented in an experimental way.

After World War II, K. O. Schmidt is known as a staff member of the "Fernmeldetechnisches Zentralamt", which was founded in 1947/49 as research unit of the German Federal Post in Darmstadt. He published a number of papers on speech transmission [20-22]. In [22, p. 61], he compared Dudley's vocoder with his own preceding ideas.

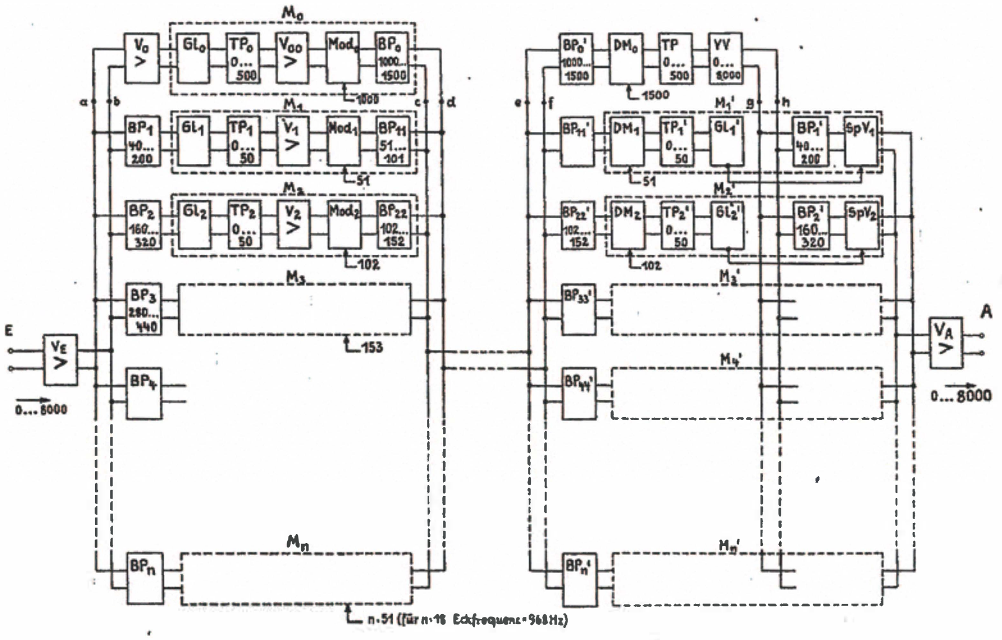


Fig. 3. Block diagram of the transmission system of K. O. Schmidt according to the patent [19]. The part below the line a-h represents the frequency channels according to the basic patent from 1932 [18]. The part above this line extracts and adds the information on voiced / unvoiced signal segments and (in the case of voiced signals) the fundamental frequency. This part forms the content of the supplementary patent from 1939 [19].

*B. The Siemens Vocoder*

The department for musical instruments in the Deutsches Museum Munich exhibits an ensemble of electronic equipment which served since 1955 as a studio for electronic music which will be discussed below in Section V. This studio includes a vocoder which was developed at the Siemens company and transferred to the studio because it was not more needed for research and development. This is obviously the rare case that we have a physically existing, historic channel vocoder in a public museum (cf. Figure 6).

We know virtually no details about the history of the Siemens vocoder before its integration in the studio. It is supposed that the development started before the end of World War II with military background. More general, it is evident from a publication [23] that Siemens was involved in the optimization of the bandwidth requirements in speech transmission since the 1930-th. We hope that more details will be revealed in the future.

Unfortunately, the real existing device in the Deutsches Museum tells us very few about the original construction at Siemens. It consists of three racks: two for the filter channels and one for control functions. A historic photograph is available at [24]. Considering the types of electronic valves and other components, it becomes clear that the device was redesigned after its transfer to the studio in the 1950-th. It is especially reported that the number of channels was raised to 20 according to the needs of musical signal processing. We do not know exactly how many channels the Siemens vocoder had before.

*C. The Vocoder of the British Post Office*

We mentioned above the existence of a secret, vocoder-based transmission line between US and UK during World War II. On the British side, the development of a vocoder at the British Post Office Research Station (located at Dollis Hill, London, since 1933) is reported for the years 1943-45 [25, Ref. 19]. A description of the device was published by R. J. Halsey and J. Swaffield in 1948 [25, 26].

The development based on H. Dudley's invention but was carried out independently. The subdivision of the frequency band was originally close to that of the Bell vocoder (cf. the curve labeled with "Dudley III" in Figure 2): The lowest band from 0 to 250 Hz was omitted, two channels with 250-400 Hz and 400-550 Hz followed, and the rest of the band was subdivided into seven channels with a bandwidth of 300 Hz each. According to [25], this nearly linear arrangement was further optimized. The final version used ten filter channels in the range of 250-3500 Hz as it is specified in Figure 2 (labeled with "British Post"). This non-linear subdivision of the frequency range proved to be more natural. The equipment was mounted in four 6 feet 6 inch racks.

J. Swaffield was later the head of the UK Government's Joint Speech Research Unit (JRSU). There, another British development of a channel vocoder was performed from 1956 to 1966. It was summarized by J. N. Holmes in [27]. It used 19 filter channels in the range of 250-4000 Hz. The construction was similar to the former vocoders but included digital transmission.

### D. The Dresden Vocoder

The Technische Hochschule (later Universität) Dresden has a long tradition in acoustics and electronics, mainly due to H. Barkhausen (1881-1956). However, a separate department of electrical engineering was founded as late as 1952, including a Laboratory of Telecommunication. The importance of the vocoder technology was recognized in that time [28]. The development of a prototype was performed in the framework of the Dr.-Ing thesis of E. Krocker (* 1927) [29, 30, 31].

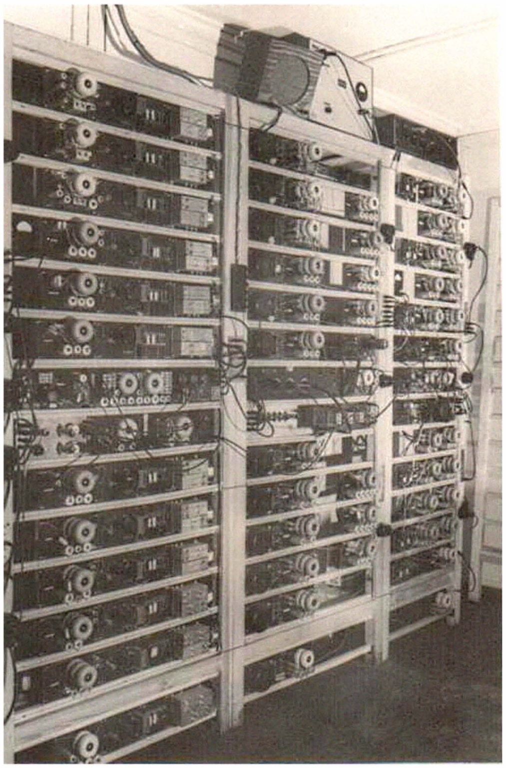

Fig. 4. Historic photograph of the Dresden vocoder [29]. The left rack contained the analyzer channels, the two right racks the synthesizer channels. The power supply was arranged behind the system.

Krocker adapted at first the channel scheme from the vocoder of the British Post Office (label "Dresden I" in Fig. 2) which was established before the concept of the critical bands in human hearing was elaborated by Feldtkeller and Zwicker in the early 1950-th [32]. It was E. Zwicker (1924-1990) personally who recommended E. Krocker to organize the frequency bands of his vocoder according to the critical bands. Considering the expenses, he implemented finally a tradeoff between the original scheme and the critical bands (label "Dresden II" in Fig. 2) which improved the syllable comprehensibility by (5 … 10) %.

The device (shown in Figure 4) was never exploited commercially. Its importance lies in the fact that it is the root for more than five subsequent decades of speech research at the TU Dresden.

### E. The Ericsson Vocoder

It should be mentioned that the Swedish Ericsson Company designed a channel vocoder in the 1950-th. The famous speech processing pioneer, G. Fant (1919-2009), reports [33] that his Speech Transmission Laboratory at the KTH was consulted for its development. Some citations of related research reports are known (e. g. [34, Ref. 104]).

## IV. Impact of Vocoders on Speech Technology

The first channel vocoders have been large and expensive. There was some doubt whether they could be widely used in commercial applications [35]. Also, the speech signal had "inhuman" quality [25] and limited comprehensibility. Krocker [31] summarizes: "The importance of the vocoder is less the frequency band compression than the potential for essential investigations on speech. The analyzer can be combined with registration equipment for the analysis of sounds, whereas the synthesizer can be combined with a control mechanism for the synthetic production of speech."


Fig. 5. Device for playing back spectrograms, TU Dresden 1973 (Historic acoustic-phonetic collection of the TU Dresden).

This was an exact prognosis. The analysis-synthesis technology proved to be a very powerful tool in speech research. The synthesizer part of a channel vocoder was used for early attempts in electronic speech synthesis. The analyzer part of the vocoder had to be replaced by a control unit. This was a manual/pedal control in the case of Dudley's famous voder [14]. Another way for controlling the synthesizer was the optoelectronical reading of a spectrogram (the graphic representation of the energy of a speech signal versus time and frequency). The first of these so-called playback devices was developed at Haskins Labs [36]. A later version which was designed at TU Dresden is still in function (Figure 5)

It became clear that there are more effective kinds of parameterization of the speech signal, and other vocoder types than the channel vocoder arose [34, 37]. Formant coding proved to be a very effective approach. Consequently, the early types of speech synthesis terminals followed the principle of formant synthesis. This development was strongly influenced by the work of G. Fant and can be illustrated using the history at different places. Formant synthesizers form four generations depending on their technology:

- manually controlled / electron valves technology
- paper tape or computer controlled / transistor technology
- process or micro computer controlled / IC technology
- embedded devices (ASIC)

We have described this way of early speech synthesis especially at the TU Dresden under the guidance of W. Tscheschner (1927-2004) in [38].

## V. Impacts on Other Fields

The audible quality of a signal which is transmitted by a vocoder can be influenced in very different ways by varying its parameters. Some audio examples from the early vocoders are available, see [39] for the Dresden vocoder. Different applications of this early "sound design" are known. E. g., the Siemens as well as the Dresden vocoder have been applied in the sound design for early science fiction movies. We will finally mention two remarkable scenarios.

### *A. The Siemens Studio for Electronic Music*

The Siemens vocoder is physically still existing (but no more able to work) because it was included in the famous Siemens Studio for Electronic Music [40] which played a prominent role in the emerging scene of electronic music. Its installation started when Siemens produced a film about the company and looked for a suited film music in 1955. The composer Josef Anton Riedl [41] created the electronic music with devices which were developed especially for this purpose. After finishing the film project in 1959 with great success, the studio was installed as a separate unit in 1960 and moved from Gauting to Munich. There it attracted the avant-garde in electronic music and sound production of that time and influenced their success considerably. Siemens finished the support in 1963, and the studio was finally closed around 1968. It came to the Deutsches Museum at Munich in 1994, where it is one of the highlights of the department of musical instruments [42] (Figure 6).

The electronic equipment of the studio included a wide variety of devices for producing, manipulating, recording, and playing musical signals. This allowed the composers to perform nearly unlimited experiments with the audible signal. The inclusion of a vocoder was very unique for that time and can be considered as a stroke of luck. The vocoder allowed to manipulate the signal separately in the different channels as well as in the kind of excitation [43]. Note that the pioneer in communication theory, W. Meyer-Eppler (1913-1960), had reported on the potential of the American vocoder at the first Tonmeister conference in Dortmund in 1949 [44]. Nowadays, electronic music is applying vocoders in large extent.

A sound studio with comparable impact existed only at the RCA with the synthesizer Mark II, but without a vocoder. It came to the Columbia University in 1957 where it still exists.

Fig. 6. Partial view of the Siemens Studio for Electronic Music at the Deutsches Museum in Munich with the three racks of the Siemens vocoder in the background. Photograph of the new arrangement, July 2010.

### *B. Analysis-by-Synthesis in Prosody Research*

The modern research activities in speech prosody, which will give the synthetic speech more naturalness and individuality, go back to vocoder experiments. The linguists A. V. Isačenko (1910-1977, a well-known slavist) and H.-J. Schädlich (* 1935, later known as a novelist) were among the first who developed models for the quantitative description of prosodic effects [45]. The English translation of their report [46] includes a disk with some of the test sentences. This test material consists of German sentences with a fundamental frequency which was manipulated to have only two values, e. g. (from [45]):

die |Vorbereitungen sind ge|troffen, |alles ist be|reit

Experiments showed that there is still enough prosodic information to recognize the correct grammatical structure of the sentences. The manipulation was performed using the Dresden vocoder with support of W. Tscheschner and later with the Ericsson vocoder, supported by G. Fant.

## VI. Conclusion

We have shown that the early vocoders had large impact on the development in different fields. Their commercial use, however, was not achieved. This figure changed drastically with the emergence of integrated circuitry and digital signal processing. Nowadays, the principle of the vocoder is widely used in signal coding for communication purposes and in musical entertainment.


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