

DECLARATION OF JUNE ANN MUNFORD (JANUARY 30, 2025)

1. My name is June Ann Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent to testify to the same.
2. I previously submitted a declaration in this proceeding, IPR2024-00393, which I understand was labeled Exhibit 1006. Paragraphs 2–5 and 29 of my prior declaration provide information regarding my qualifications, background on MARC records, and my engagement, which I incorporate herein.
3. In paragraphs 6–9 of my prior declaration, I discussed the Jacobsen article, “An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network” by Krista S. Jacobsen and John M. Cioffi as published in *National Cable Television Association 1994 Technical Papers* (“Jacobsen” or “the Jacobsen article”). I understand that the Petitioner submitted the Jacobsen article as Exhibit 1016. Copies of the Jacobsen MARC record and the Jacobsen article, Appendices JACOBSEN01 and JACOBSEN02, respectively, which I discussed in my prior declaration, are attached to this declaration for completeness.
4. I understand that after my prior declaration, the Patent Owner submitted a Patent Owner Response (“PO Response”) that contends “[t]here is no evidence that a POSITA would have been able to identify Jacobsen.” PO Response at 45–47 (subheading 1). I also understand that the Patent Owner contends that “MARC evidence does not establish when Jacobsen was cataloged in any library.” PO Response at 47–49 (subheading 2).
5. Petitioner’s counsel has asked me to review the Patent Owner Response and to assess the

Response's arguments. I provide my views below.

6. The Patent Owner Response states that Jacobsen was "inaccessible to a POSITA." PO Response at 45 ("Ms. Munford has specialized training in information science that a POSITA would not have and is thus able to locate materials that would be inaccessible to a POSITA."). Although I am not a technical expert, my analysis of Jacobsen is based upon the materials that are included in a research library that is open to the general public. Reasonably diligent, interested POSITAs would be able to interact with resources owned by a research library to access Jacobsen. If necessary, a POSITA could also use the assistance of the employees of the Linda Hall Library, allowing any potential POSITA to access and utilize the breadth of library services without possessing specialized library-science knowledge. Similarly, POSITAs would be able to ask local librarians for assistance, who could then interact with employees of the Linda Hall Library, for example, to obtain a given resource, including Jacobsen, if they were unable to locate the resource alone.
7. I note that The Linda Hall Library is a leading independent science research library, based in Kansas City, Missouri. The library collects many scientific journals, conference proceedings, monographs, and technical reports. The Linda Hall Library is a public library open to any private individual or business, allowing any member of the public to visit the library to gain access to its collection. Linda Hall Library also offers off-site options for accessing the library's collection such as the library's document delivery service or interlibrary loan service. To facilitate patrons exploring the library's collection, Linda Hall librarians offer typical library services such as fact-finding research and library catalog help in addition to more detailed projects such as in-person classes and

research guides.

8. The Patent Owner Response also states that “[t]here no testimony that any POSITA would be familiar with or know how to use MARC records.” PO Response at 46. This view contradicts my own experience. MARC records are created for usage in a library catalog, a resource commonly made available to members of the public. Library catalogs allow any interested member of the public to use simple and advanced search techniques to discover materials within a library’s collection. Catalog search results are generated directly from fields indexed in MARC records, even if users do not directly interact with the MARC record itself in any meaningful way. Thus, although a library user may not know how to create or maintain a MARC record, they still use the MARC record when they search a library catalog.
9. The Patent Owner Response also states, “Petitioner provides no other evidence that Jacobsen was publicly available at any time that would qualify it as prior art to the ‘518 Patent.” PO Response at 46.
10. Attached hereto as Appendix JACOBSEN05 is a true and correct copy of a paper entitled “Synchronized DMT for Multipoint-to-point Communications on HFC Networks” by K.S. Jacobsen, John A.C. Bingham and J.M. Cioffi as published in *Proceedings of GLOBECOM ‘95*. I secured this paper myself from <https://ieeexplore.ieee.org/abstract/document/502547>. The ‘Date of Conference’ field visible on page 1 of Appendix JACOBSEN05 indicates this paper was presented at the GLOBECOM 1995 conference, held from November 14–16, 1995. Endnote [1] on page 8 of Appendix JACOBSEN05 contains a citation to “An Efficient Digital Modulation

Scheme for Multimedia Transmission on the Cable Television Network” by Krista S. Jacobsen and John M. Cioffi as published in *National Cable Television Association 1994 Technical Papers*.

11. Attached hereto as Appendix ARMADA01 is a true and correct copy of a paper entitled “Rapid prototyping of a test modem for terrestrial broadcasting of digital television” by A. Garcia Armada and M. Calvo Ramon as published in *IEEE Transactions on Consumer Electronics* November 1997. I secured this paper myself from <https://ieeexplore.ieee.org/abstract/document/642377/>. The ‘Date of Publication’ field visible on page 1 of Appendix ARMADA01 indicates this paper was published as of November 30, 1997. Endnote [21] on page 16 of Appendix ARMADA01 contains a citation to “An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network” by Krista S. Jacobsen and John M. Cioffi as published in *National Cable Television Association 1994 Technical Papers*.
12. In my view, articles published subsequent to “An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network” also show that Jacobsen was publicly available at least as of 1995 and certainly no later than 1997. For example, “Synchronized DMT for Multipoint-to-point Communications on HFC Networks” by K.S. Jacobsen, John A.C. Bingham and J.M. Cioffi as published in *Proceedings of GLOBECOM ‘95* was presented at the GLOBECOM ‘95 conference in November 1995 and cites Jacobsen on page 8. Additionally, “Rapid prototyping of a test modem for terrestrial broadcasting of digital television” by A. Garcia Armada and M. Calvo Ramon as published in *IEEE Transactions on Consumer Electronics* November 1997 was published in 1997 and cites Jacobsen on page 16.

13. The Patent Owner Response also states, “Ms. Munford has specialized training in information science that a POSITA would not have and is thus able to locate materials that would be inaccessible to a POSITA.” PO Response at 47. I disagree with this statement. As noted above, reasonably diligent POSITAs would be able to ask local librarians for assistance in locating a given resource, such as Jacobsen, should they not be able to locate it entirely independently.
14. The Patent Owner Response also states, “MARC records may be edited after being generated.” PO Response at 48. I agree that a MARC record can be edited after the record’s initial creation, although with some important clarifications. For example, MARC records are regularly updated to ensure greater accuracy and reflect changes made to the library’s collection. A MARC record may also be edited to add additional subject headings, fix typographical errors or reflect changes made to the work’s physical status—but these types of edits would not typically involve a header field such as 008. As my determination of Jacobsen’s availability is based upon the record 008 field, I will note that I have never edited a 008 field and have never witnessed another librarian edit an 008 field, and I would consider that to be a highly unusual and unlikely field to edit. For example, first, the 008 field is a header field, largely designed to interact with cataloging software on a level invisible to the end user. Catalog functions such as searching, reserving or circulating materials do not rely on this field. Second, header fields are frequently auto-generated by a librarian’s cataloging software. Editing this field would be similar to editing a Word doc’s metadata. Third, the 008 field does not index information that would need to be regularly updated, unlike fields describing such bibliographic details as author, subject heading or call number.

15. Finally, the Patent Owner Response also states, “the creation of the MARC record is not evidence that the version of the journal containing the Jacobsen reference was publicly available as of the MARC record’s creation date.” PO Response at 48. This statement shows a fundamental misunderstanding of the Linda Hall Library record used to authenticate the Jacobsen reference. Jacobsen is cataloged by the Linda Hall Library as a periodical, not a journal. Further, in my experience, librarians often catalog materials as periodicals when that publication is expected to release several volumes in succession. Librarians create the MARC record upon acquiring the material and then append new volumes to the record to ensure expediency for time-sensitive materials. As the Linda Hall Library’s record indicates the proceedings were acquired over a year *after* the 1994 National Cable Television Association Workshop, it is likely that the material was acquired with minimal concern for expediency, not that the material was unavailable. Further, the cataloging of this record, represented as Appendix JACOBSEN01, indicates that the 1994 NCTA Workshop volume containing Jacobsen was consulted during the creation of this record: field 500 notes that the record’s description was based on the 1994 edition of these conference proceedings (e.g., “Description based on: 43rd (1994).”).
16. Additionally, attached hereto as Appendix JACOBSEN04¹ is a true and correct copy of the MARC record for National Cable Television Association Technical Papers as held by the Canadian Federal Science Libraries Network. I secured this record myself from the library’s public catalog. The ‘Location Items’ field visible on page 2 of Appendix JACOBSEN01 indicates that this collection includes the 1994 edition of National Cable

¹ My first declaration provides an Appendix JACOBSEN03 for a different Jacobsen article.

Television Association Technical Papers containing “An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network”. The MARC record contained within Appendix JACOBSEN04 accurately describes the title, author and publisher of National Cable Television Association Technical Papers.

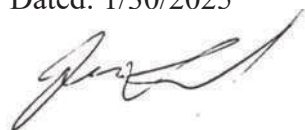
17. Accordingly, in view of the above, I maintain that the 008 field of the MARC record in Appendix JACOBSEN01 indicates the date of record creation. The 008 field of Appendix JACOBSEN01 indicates the Linda Hall Library first acquired this book as of September 19, 1995. Considering this information, it remains my determination that *National Cable Television Association 1994 Technical Papers* and therefor “An Efficient Digital Modulation Scheme for Multimedia Transmission on the Cable Television Network” was made available to the public shortly after its initial acquisition in September 1995.
18. Further, as the ARMADA01 and JACOBSEN05 (GLOBECOM ‘95) articles show, Jacobsen was publicly available at least as of 1997, because these articles cite the Jacobsen article.
19. I have reviewed Exhibit DISH-1037, “New Technologies Take the Network Home” by George Lawton as published in IEEE Computer March 1999.
20. Attached hereto as Appendix LAWTON01 is a true and correct copy of the MARC record for IEEE Computer as held by the Penn State University Library. I secured this record myself from the library’s public catalog. The MARC record contained within Appendix LAWTON01 accurately describes the title, publisher and ISSN number of IEEE Computer. The Availability field present on page 5 of this record indicates the library’s collection includes the March 1999 issue of IEEE Computer containing “New

Technologies Take the Network Home”.

21. Attached hereto as Appendix LAWTON02 is a true and correct copy of “New Technologies Take the Network Home” as published in IEEE Computer as held by the Penn State University Library. These scans were secured from the library’s collection. In comparing Exhibit DISH-1037 to Appendix LAWTON02, it is my determination that Exhibit DISH-1037 is a true and correct copy of “New Technologies Take the Network Home” by George Lawton as published in IEEE Computer.
22. The 008 field of the MARC record in Appendix LAWTON01 indicates the date of record creation. The 008 field of Appendix LAWTON01 indicates the Penn State University Library first acquired IEEE Computer as of March 29, 1982 and held the journal in perpetuity until the publication of “New Technologies Take the Network Home”. Considering this information, it is my determination that IEEE Computer March 1999 and therefore “New Technologies Take the Network Home” was made available to the public shortly after its initial publication in March 1999.
23. I have reviewed Exhibit DISH-1038, Voice & Data Communications Handbook by Regis J. Bates, et al.
24. Attached hereto as Appendix BATES01 is a true and correct copy of the MARC record for Voice & Data Communications Handbook as held by the University of Pittsburgh Library. I secured this record myself from the library’s public catalog. The MARC record contained within Appendix BATES01 accurately describes the title, author, publisher, and ISBN number of Voice & Data Communications Handbook.

25. Attached hereto as Appendix BATES02 is a true and correct copy of selections from Voice & Data Communications Handbook as held by the University of Pittsburgh Library. These scans were secured from the library's collection. In comparing Exhibit DISH-1038 to Appendix BATES02, it is my determination that Exhibit DISH-1038 is a true and correct copy of Voice & Data Communications Handbook by Regis J. Bates, et al.
26. The 008 field of the MARC record in Appendix BATES01 indicates the date of record creation. The 008 field of Appendix BATES01 indicates the University of Pittsburgh Library first acquired Voice & Data Communications Handbook as of August 27, 2001. Considering this information, it is my determination that Voice & Data Communications Handbook was made available to the public shortly after its initial acquisition as of August 27, 2001.
27. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 1/30/2025



June Ann Munford

APPENDIX ARMADA 01



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This paper introduces rapid prototyping of a complex system and the difficulties that appear when a real-time prototype of such a system is approached. These concepts are applied to the construction of a test modem for terrestrial broadcasting of digital television, in which orthogonal frequency division multiplexing (OFDM) is the transmission technique. The possibility of reducing the number of sub-carriers in the OFDM signal and obtaining enough information about the system performance in hostile environments (multipath, phase noise, non-linear, ...) is considered and discarded. As a conclusion, a non-real time prototype is presented which allows one to optimize parameters, verify the possibility of implementation and evaluate subjective qualities.

Published in: IEEE Transactions on Consumer Electronics (Volume: 43 , Issue: 4, November 1997)**Page(s):** 1100 - 1109**DOI:** 10.1109/30.642377**Date of Publication:** 30 November 1997 ?**Publisher:** IEEE

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References is not available for this document.

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RAPID PROTOTYPING OF A TEST MODEM FOR TERRESTRIAL BROADCASTING OF DIGITAL TELEVISION

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Abstract—This paper introduces Rapid Prototyping of a complex system and the difficulties that appear when a real-time prototype of such a system is approached. These concepts are applied to the construction of a test modem for Terrestrial Broadcasting of Digital Television, in which Orthogonal Frequency Division Multiplexing (OFDM) is the transmission technique.

The possibility of reducing the number of sub-carriers in the OFDM signal and obtaining enough information about the system performance in hostile environments (multipath, phase noise, non-linear, ...) is considered and discarded. As a conclusion, a non-real time prototype is presented which allows one to optimize parameters, verify the possibility of implementation and evaluate subjective qualities.

1. INTRODUCTION

The research in the area of VHF/UHF terrestrial broadcasting is coming nowadays to a completely digital implementation both in the US (Grand Alliance) [1] and Europe. The future digital systems must be compliant with very strict requirements in terms of bit error rates. Besides, they must fight multipath, be friendly to existing analog systems, cope with the interference caused by them [2] and fit in the assigned available bandwidths.

The complexity involved in achieving these objectives forces us to test and optimize the system before its final implementation. This is normally done by means of analysis and simulation, postponing the construction of prototypes to the last steps in the design cycle. However, prototyping in earlier stages allows us to:

- test more parameters in a shorter time
- optimize parameters in real time conditions
- evaluate subjective characteristics
- verify the possibility of implementation.

For these reasons there is an increasing interest in Rapid Prototyping of communications systems, with the main objective of reducing the design cycle and improving the products quality.

In the European DVB Project (Digital Video Broadcasting), founded by initiative of more than 190 organizations, the standards for digital television broadcasting have been specified for the different transmission media: satellite (DVB-S), cable (DVB-C) and terrestrial (DVB-T) [3,4].

The later is a result of the RACE Project dTTb (Digital Television for Terrestrial Broadcasting), which has

covered all the aspects of digital television terrestrial broadcasting in Europe, with the work of 30 partners from 10 different countries [5].

The system specified within the dTTb Project is very complex [4,5] (see Figure 1 and Figure 2). Taking as an input the signal coming from an MPEG-2 encoder [6], all the elements for its correct transmission and reception are defined, adapting the signal to the terrestrial channel. With this aim, a combined encoding and modulation process [7] is applied to the data source, with different coding rates [8,9] (which imply different bit rates), according to the channel characteristics and the expected quality at the receiver. Besides, different services, depending on the quality of the received TV signal (standard, enhanced and high definition), several configurations (by combination of these services) and various coding schemes are defined.

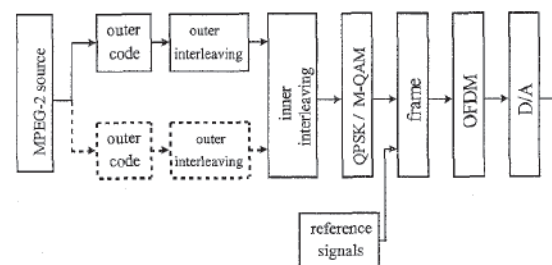


Figure 1 dTTb transmitter block diagram

To summarize, transmitter and receiver must be very flexible and this can only be achieved if most of the elements are implemented in software. This idea leads to the Software Radio concept [10,11] in which as many functions as possible are programmed by bringing A/D and D/A converters [12] the closer to the antenna.

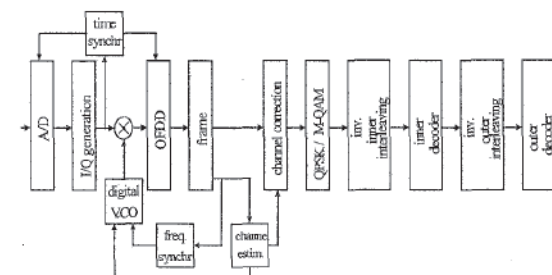


Figure 2 dTTb receiver block diagram

In this context, we have developed a methodology to allow the use of software design tools to implement in a rapid and efficient way communications systems prototypes using digital signal processors (DSPs). This

Contributed Paper

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methodology has been applied to the construction of a prototype for the European Digital Television for Terrestrial Broadcasting System (dTTb).

None of the published works in this field [13-18], has approached the application of these concepts to such a system. However, its complexity and the fact that we are dealing with rapidly emerging technologies configure it as a clear example of the Rapid Prototyping advantages.

Rapid Prototyping of a complex system presents some difficulties, which depend on the system characteristics. In the next section, the transmission technique used in the DVB-T standard (Orthogonal Frequency Division Multiplexing) is introduced and the problems associated with the construction of a prototype are identified. We propose two different solutions and discuss their feasibility.

Finally, the solution adopted and the prototype constructed using two Ariel MM-96 (board which includes two Motorola DSP96002) are presented.

2. RAPID PROTOTYPING OF AN OFDM-BASED SYSTEM

The European system for Terrestrial Broadcasting of Digital Television has strong requirements. It has to be able to cope with multipath, friendly and robust to existing analog systems and make efficient use of the available bandwidth. These reasons have led to the adoption of the Orthogonal Frequency Division Multiplexing (OFDM) technique for the signal transmission.

In this section, the OFDM concept is introduced and the problems associated to its rapid implementation are identified.

2.1 Orthogonal Frequency Division Multiplexing

Among the activities of the latest European RACE and ACTS projects, there has been an increasing interest in OFDM (Orthogonal Frequency Division Multiplexing) as a means of combating impulsive noise and multipath effects and making fuller use of the system available bandwidth.

OFDM is one of the best alternatives to alleviate the multipath effects in mobile communications [19]. For reception in built-up areas with delay spreads of some microseconds, the channel is highly frequency selective and sophisticated equalization techniques are required to achieve high bit rate transmissions. However, a combination of OFDM and coding associated with interleaving in the frequency domain (COFDM) can take advantage from the diversity associated to multipath [20]. Besides, multi-carrier systems have been proved to be more computationally efficient than single-carrier systems with equalization under some multipath channel conditions [21].

In an OFDM system the spectrum associated to each elemental data is a small portion of the total bandwidth, which is divided in N sub-channels. Each of them is modulated with one symbol and they are all multiplexed

in frequency.

If T represents the OFDM symbol duration, that is: $T = \frac{1}{B \cdot N}$, the N carriers are placed in the frequencies:

$$f_k = f_0 + k / T, \quad k = 1, 2, \dots, N - 1$$

A higher spectral efficiency is achieved because the different sub-channels are allowed to overlap. Orthogonality between them simplifies the separation process in the receiver, allowing the use of the Discrete Fourier Transform [22].

2.2 Implementation of OFDM using the Discrete Fourier Transform

The complex envelope of the transmitted OFDM signal, sampled with sampling frequency $f_s = \frac{1}{B}$, is:

$$s(n) = \sum_{m=-\infty}^{\infty} \sum_{n=N_g}^{N-1} \sum_{k=0}^{N-1} s_{m,k} \cdot e^{j \frac{2\pi}{N} kn} \prod (n - m(N + N_g))$$

This means that every OFDM symbol has $N + N_g$ values which are the N obtained by an N -point Inverse Discrete Fourier Transform (IDFT) plus an added Time Guard of N_g (the last N_g samples of the IDFT are added at the beginning of each symbol) in order to cope with the inter-symbol interference (ISI) caused by multipath delay spread. $\Pi(n)$ is a rectangular pulse of duration $N + N_g$ samples.

The Time Guard is eliminated in the receiver and in the absence of channel or noise impairments, the signal is Orthogonal Frequency Division Demultiplexed in the receiver by means of an N -point Discrete Fourier Transform (DFT):

$$\begin{aligned} \frac{1}{N} \sum_{r=0}^{N-1} s(r) \cdot e^{-j \frac{2\pi}{N} rm} &= \frac{1}{N} \sum_{r=0}^{N-1} \sum_{k=0}^{N-1} s_k \cdot e^{j \frac{2\pi}{N} kr} \cdot e^{-j \frac{2\pi}{N} rm} = \\ &= \frac{1}{N} \sum_{k=0}^{N-1} s_k \sum_{r=0}^{N-1} e^{j \frac{2\pi}{N} r(k-m)} = s_k \end{aligned}$$

because

$$\frac{1}{N} \sum_{r=0}^{N-1} e^{j \frac{2\pi}{N} r(k-m)} = \begin{cases} 1 & k-m=cN, c \text{ integer} \\ 0 & \text{otherwise} \end{cases}$$

Summarizing, the OFDM and OFDD processes involve an inverse DFT in the transmitter and a DFT in the receiver. Both can be efficiently implemented by using the Fast Fourier Transform algorithm (FFT).

2.3 Rapid Prototyping of OFDM

OFDM has been proposed and is being tested for the Digital Television for Terrestrial Broadcasting System (dTTb) [5] considering two possible values for the number N of sub-carriers: 2048 (2K) and 8192 (8K). The sampling frequency in this system is $f_s = 64/7$ MHz = 9.142857 MHz, which means that the sub-carrier spacing $\Delta f = f_s/N$ and the symbol time T are:

- 8K mode: $\Delta f = 1.116$ KHz, $T = 896$ μ s.
- 2K mode: $\Delta f = 4.464$ KHz, $T = 224$ μ s.

Real Time Prototyping of a system with these parameters implies implementation of 2K and 8K FFTs in the OFDM symbol time. However, the MM-96 with a 40 MHz clock has a benchmark of 2420 μ s for a Radix 2 Cooley-Tukey Decimation in Time complex FFT of 2K points and 11320 μ s for a 8K one [23,24].

Besides, Rapid Prototyping implies that the code will not be thoroughly optimized, and the use of several processors in parallel will exhibit inefficiencies which will not allow us to obtain a maximum speed-up [25].

These circumstances lead to the consideration of the impossibility of real time implementation with a low number of DSPs. We propose two alternative solutions:

- ① Scaling some parameter in the system so that a real time implementation is possible:

Depending on the system characteristics, the reduction of some parameter can lead to a realizable prototype without variation of the main system properties. In our case, we will try reducing the number of sub-carriers and study the implications in the OFDM signal characteristics.

As Figure 3 shows, a system with 128 sub-carriers could be a good approach to a real time implementation.

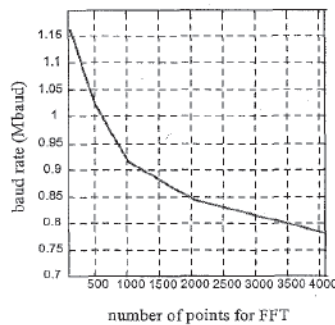


Figure 3 achievable baud rate vs. FFT length with Ariel MM-96 DSP

- ② Non real time implementation of the whole system:

Rapid Prototyping can offer some advantages even if the prototype can not run in real time. In some cases, it can still be possible to optimize parameters, evaluate subjective quality and verify the possibility of implementation.

In the following, we will discuss the viability of both solutions for the construction of a Digital Television Terrestrial Broadcasting test prototype.

3. IMPLICATIONS OF THE REDUCTION OF THE NUMBER OF SUB-CARRIERS IN AN OFDM SYSTEM

In order to examine the effects of the reduction of the number of sub-carriers in an OFDM system, we will consider the following main points which affect the

OFDM system performance:

- channel effects
- phase noise
- synchronization
- non-linear effects

3.1 Channel effects in OFDM

If the transmitted signal defined in 2.2 is affected by a channel with impulse response $h(t)$, assuming that the ISI is eliminated with the time guard, the received signal is:

$$r(n) = s(n) \otimes h(n) = \sum_{m=0}^{N-1} s(m) \cdot h(n-m) = \sum_{m=0}^{N-1} h(m) \cdot s(n-m)$$

and it is Orthogonal Frequency Division Demultiplexed:

$$\begin{aligned} \frac{1}{N} \sum_{r=0}^{N-1} r(r) \cdot e^{-j\frac{2\pi}{N}rn} &= \frac{1}{N} \sum_{r=0}^{N-1} \sum_{m=0}^{N-1} h(m) \cdot s(r-m) \cdot e^{-j\frac{2\pi}{N}rn} = \\ &= \frac{1}{N} \sum_{r=0}^{N-1} \sum_{m=0}^{N-1} h(m) \sum_{l=0}^{N-1} s_l \cdot e^{j\frac{2\pi}{N}l(r-m)} \cdot e^{-j\frac{2\pi}{N}rn} = \\ &= \frac{1}{N} \sum_{r=0}^{N-1} \sum_{l=0}^{N-1} s_l \cdot e^{j\frac{2\pi}{N}l(r-n)} \sum_{m=0}^{N-1} h(m) \cdot e^{-j\frac{2\pi}{N}lm} = \\ &= \frac{1}{N} \sum_{l=0}^{N-1} s_l \cdot H(l) \sum_{r=0}^{N-1} e^{j\frac{2\pi}{N}l(r-n)} = H(n) \cdot s_n \end{aligned}$$

with $H(n) = \sum_{m=0}^{N-1} h(m) \cdot e^{-j\frac{2\pi}{N}nm}$, the DFT of the

channel impulse response.

This means that the channel affects the demultiplexed signal by multiplying each symbol by the frequency response corresponding to this symbol sub-carrier $H(n)$.

The OFDM signal distribution can be used to insert pilot carriers for channel estimation and correction. The channel frequency response for all the information carriers can be obtained by interpolation from the values provided by these pilots.

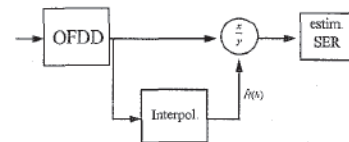


Figure 4 channel estimation at the receiver

The channel correction can thus be accomplished by division of the OFDD signal by an estimation of $H(n)$ (Figure 4). In order to obtain this estimation (FFT of the channel impulse response), two types of pilots are inserted in the OFDM frame: scattered and continual pilots [5,26].

Scattered pilots occupy different carrier positions on each OFDM symbol, with a periodicity of 4 symbols. Continual pilots are inserted in identical fixed positions for every OFDM symbol.

From the scattered pilot distribution, which gives the channel FFT coefficients for discrete carrier indexes and time instants, time interpolation is applied so as to obtain the coefficients for every time instant and discrete carrier indexes. This means that if in symbol n a given carrier k is a pilot, coefficients are obtained corresponding to carrier k for all symbols.

Besides, continual pilots are used to estimate a common phase error, which can appear due to the local oscillator's phase noise and does not depend on the carrier index, but varies randomly between OFDM symbols.

The OFDM system performance has been analyzed considering the dependence of the channel effects and the pilot-based correction capabilities with the number of sub-carriers. Two channel models have been considered, which correspond to fixed reception (F1) and portable reception (P1) in the European Digital Television for Terrestrial Broadcasting system (dTtb) [5,26].

3.1.1 Inter-Symbol Interference (ISI):

In order to cope with multipath delay spread, a Time Guard is added to the OFDM signal so as to absorb the inter-symbol interference (ISI). This Time Guard is a cyclic extension of the signal built by adding the last N_g samples of the OFDM symbol at the beginning, giving a total OFDM symbol duration of $N+N_g$ samples ($T+T_g$ seconds).

If the Time Guard is longer than the channel impulse response, the ISI is contained in the first N_g samples of the OFDM symbol, which are discarded before the demultiplexing via FFT in the receiver.

However, if the Time Guard is not long enough, some ISI will be present.

This Time Guard duration is limited by the information rate: the longer the Time Guard, the lower the ratio

$$\frac{\text{information bits}}{\text{total OFDM duration}}$$

Since the OFDM duration depends on the number of sub-carriers N , if the sub-carrier spacing is small (many sub-carriers), the Time Guard can be larger without affecting the information rate seriously.

The Time Guards proposed in dTTb for 2K and 8K sub-carriers, defined as the ratio between the guard duration and the OFDM symbol time, are shown in Table 1. Besides, 128 sub-carriers have been considered.

Table 1 OFDM Time Guards

	1/4	1/8	1/16	1/32
8 K ($T=896\mu\text{s}$)	224 μs	112 μs	56 μs	28 μs
2 K ($T=224\mu\text{s}$)	56 μs	28 μs	14 μs	7 μs
128 ($T=14\mu\text{s}$)	3.5 μs	1.75 μs	0.875 μs	0.4375 μs

No ISI will appear in any case when using 2K or 8K sub-carriers (the impulse response duration of both F1

and P1 channels is 5.42 μs), but we would need to increase the Guard Time ratio up to 1/2 (7 μs) to avoid ISI when using 128 sub-carriers. However this would mean a 33% decrease of the information rate, which we normally can not afford.

3.1.2 Channel distortion without ISI

If the ISI is eliminated with the Time Guard, the only channel distortion caused to the signal is the multiplication by the channel frequency response. This means that when the channel presents an attenuation in some frequency, the corresponding symbol will be corrupted (unless some channel correction is applied).

This effect is independent of the sub-carrier spacing, as Figure 5 shows.

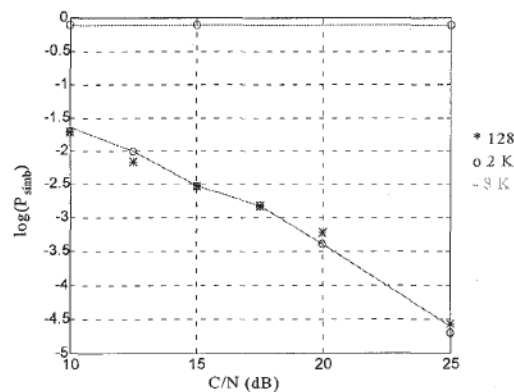


Figure 5 channel effects for 8K, 2K and 128 sub-carriers (P1: upper curves, F1: lower curves)

3.1.3 Channel correction capabilities

The channel estimation is accomplished by means of interpolation using the pilot structure introduced in the OFDM frame (as explained at the beginning of this section).

The accuracy of the estimation depends strongly on the number of sub-carriers. The reason is that if this number is small, not enough pilots will be included in the frame to interpolate the channel frequency response, as it happens with the 128 sub-carrier system. Obviously the number of pilots has to be limited in order to maintain an adequate information rate.

Table 2 shows the power of the estimation error, computed this error as the difference between the channel frequency response and the channel estimation.

Table 2 power of estimation error

	128	2K	8K
F1 channel	0.14	0.03	0.002
P1 channel	1.5	0.2	0.017

Although the error is bigger when using 2K than with 8K sub-carriers, because less pilots can be used for

estimation (the difference is one order of magnitude), channel correction is still possible. However, this is not the case when using only 128 sub-carriers, as shown in Figure 6.

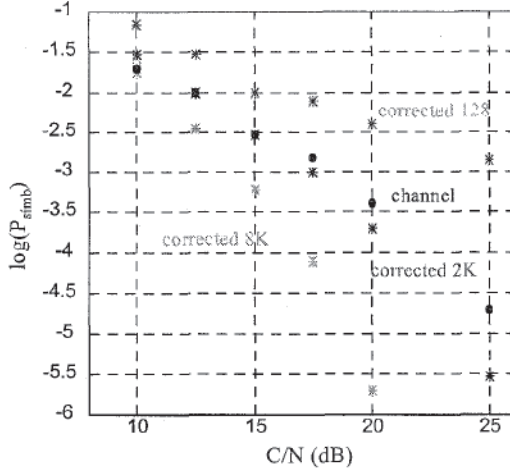


Figure 6 SER versus C/N with and without channel correction

In this figure, Symbol Error Rate (SER) is plotted versus carrier to noise power ratio (C/N) for the F1 channel. The channel output SER and the corrected SER are compared.

All systems show a similar SER when no correction is applied (with 'o' in Figure 6) as mentioned above (section 3.1.1), but they exhibit different correction capabilities ('*' in Figure 6). While the improvement is more than 5 dB with 8K, with 2K is only about 2 dB and with 128 sub-carriers, the SER is even worse when channel correction is applied than without correction.

This means that a number of 128 sub-carriers can not be used in a multipath environment.

3.2 Phase noise effects in OFDM

All superheterodyne receivers use one or more local oscillators to convert an input frequency to an intermediate frequency before the signal is demodulated. Both the mixer used for converting the signal's frequency and the local oscillator will distort the signal and limit the receiver's ability to recover the modulation on a signal [27].

Although the mixer degradation can be minimized by proper design in the rest of the receiver, the phase noise introduced by the local oscillator cannot be decreased except by improving the performance of the oscillator. Therefore the importance of determining how much phase noise a receiver can admit maintaining the required performance.

Assuming that the channel is flat, the transmitted signal defined in 2.2 is only affected by phase noise $\phi(n)$ at the receiver:

$$r(n) = s(n) \cdot e^{j\phi(n)}$$

and it is Orthogonal Frequency Division Demultiplexed by means of a Discrete Fourier Transform:

$$y(k) = \frac{1}{N} \sum_{m=0}^{N-1} r(m) \cdot e^{-j\frac{2\pi}{N}km} = \frac{1}{N} \sum_{m=0}^{N-1} e^{j\phi(m)} \sum_{r=0}^{N-1} s_r \cdot e^{j\frac{2\pi}{N}rm} \cdot e^{-j\frac{2\pi}{N}km} =$$

$$= \frac{1}{N} \sum_{m=0}^{N-1} e^{j\phi(m)} \sum_{r=0}^{N-1} s_r \cdot e^{j\frac{2\pi}{N}(r-k)m} = \frac{1}{N} \sum_{r=0}^{N-1} s_r \sum_{m=0}^{N-1} e^{j\phi(m)} \cdot e^{j\frac{2\pi}{N}(r-k)m}$$

In order to separate the signal and noise terms, let us suppose that $\phi(m)$ is small, so that

$e^{j\phi(m)} \approx 1 + j\phi(m)$. In this case:

$$\begin{aligned} y(k) &\approx \frac{1}{N} \sum_{r=0}^{N-1} s_r \sum_{m=0}^{N-1} e^{j\frac{2\pi}{N}(r-k)m} + \frac{j}{N} \sum_{r=0}^{N-1} s_r \sum_{m=0}^{N-1} \phi(m) e^{j\frac{2\pi}{N}(r-k)m} = \\ &= s_k + \frac{j}{N} \sum_{r=0}^{N-1} s_r \sum_{m=0}^{N-1} \phi(m) e^{j\frac{2\pi}{N}(r-k)m} = s_k + e_k \end{aligned}$$

Thus we have an error term e_k for each sub-carrier which results from some combination of all carriers and is added to the useful signal. Let us analyze more deeply this noise contribution:

a) If $r=k$:

$$\frac{j}{N} \sum_{r=0}^{N-1} s_r \sum_{m=0}^{N-1} \phi(m) = j \frac{s_k}{N} \sum_{m=0}^{N-1} \phi(m) = j \cdot s_k \cdot \Phi$$

So we have a common error added to every sub-carrier which is proportional to its value multiplied by a complex number $j\Phi$, that is a rotation of the constellation.

This angle results from an average of phase noise over all of them (which implies low frequencies of phase noise spectrum) and, since it is constant for all sub-carriers, it can be corrected with the information provided by pilots.

b) If $r \neq k$:

$$\frac{j}{N} \sum_{r=0}^{N-1} s_r \sum_{m=0}^{N-1} \phi(m) \cdot e^{j\frac{2\pi}{N}(r-k)m}$$

This term corresponds to the summation of the information of the $N-1$ sub-carriers each multiplied by some complex number which comes from an average of phase noise with a spectral shift. The result is also a complex number which is added to each sub-carrier's useful signal and has the appearance of white noise. It is normally known as inter-carrier interference (ICI) or loss of orthogonality.

3.1.1 Error performance

Simulations have been run so as to study the influence of phase noise in the reception of OFDM signals and the phase noise error correcting capabilities of pilot-based channel correction. The assumptions and simplifications made in the previous analysis to understand the system behavior have not been applied to simulations, so results can be obtained for any phase noise and channel situations.

We have modeled phase noise as a phase modulation of the carrier. The modulating signal is a white random

process with a uniform or gaussian pdf, which has been filtered so as to analyze the influence of the phase noise correlation characteristics in the signal quality. Results are presented using the reciprocal of the filtered phase noise bandwidth: T_ϕ and comparing it to the OFDM symbol duration: T_{OFDM} .

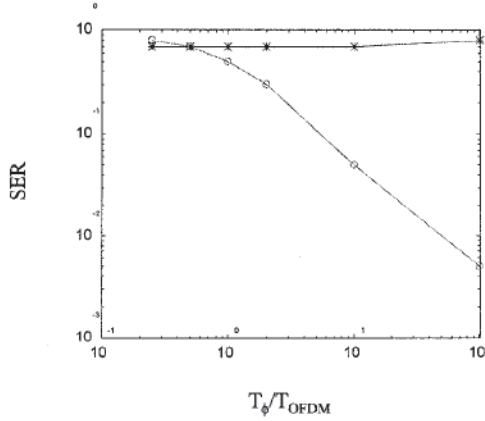


Figure 7 phase noise in OFDM: * corrupted signal, o corrected signal

Figure 7 shows the behavior of an OFDM system corrupted by uniform phase noise when using pilot-based channel correction. As it can be observed, phase noise effects can be corrected when the phase noise variations are much slower than the OFDM period. In this case the common phase error dominates over the ICI.

The same curves are obtained when considering any number of sub-carriers if the phase noise period is normalized with respect to OFDM symbol duration.

When $T_\phi < T_{OFDM}$, pilot based channel correction is not able to correct phase noise errors and it can even increase the SER.

If the period of phase noise variations is expressed in seconds, the results are those of Figure 8.

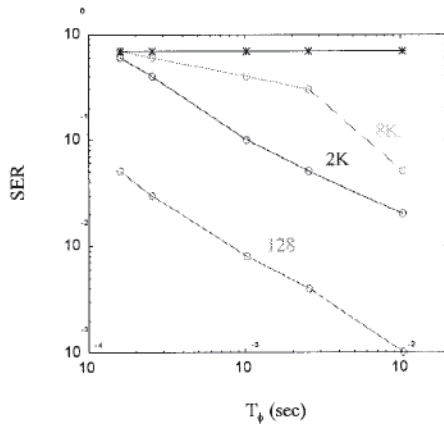


Figure 8 OFDM with different numbers of sub-carriers: * corrupted, o corrected

The symbol error rate (SER) degradation caused by phase noise is the same for 128, 2K and 8K systems. However, the correction capabilities, as indicated above,

depend on the phase noise to OFDM time ratios. It is clear that for a given phase noise bandwidth, the performance of a 128 sub-carrier OFDM system is much better than that corresponding to a bigger number of sub-carriers, provided that the phase noise variations are much slower than the OFDM period. This means that the phase noise bandwidth should be less than $1/14\mu s \approx 71$ KHz. Otherwise, the pilot structure will not be usable to correct phase noise errors.

3.3 OFDM synchronization

The OFDM synchronization system in the receiver must execute the following functions:

- Decide which number of sub-carriers is using the system (2K / 8K).
- Estimate which is the Time Guard value among the various possibilities.
- Adjust the FFT starting position.

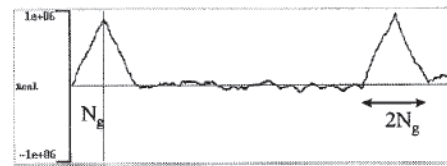
They are accomplished taking profit of the OFDM signal correlation properties after insertion of the Time Guard.

In fact, there are N_g samples of the signal which are repeated within an interval of $N+N_g$ samples. This property can be used to synchronize the receiver by making the following correlation:

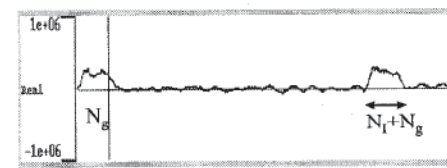
$$corr(n) = \sum_{k=n-N_I+1}^n s(k) \cdot s^*(k-N)$$

Where N is the number of points in the transmitter IFFT (number of sub-carriers) and N_I is a parameter which must be chosen theoretically equal to and never bigger than the Guard Time N_g .

In the absence of noise and multipath, this correlation presents the aspect shown in Figure 9. When $N_I = N_g$, there is a peak at the beginning of the useful OFDM symbol. The peak is replaced by a flat top of duration $N_I + N_g$ when $N_I < N_g$, which ends also at the beginning of the useful symbol.



(a) $N_I = N_g = 256$



(b) $N_I = 64, N_g = 256$

Figure 9 OFDM (2K) correlation with different N_I

Noise enhances the correlation levels between the peaks

(Figure 10). Multipath has more noticeable effects as Figure 11 shows for an OFDM signal after P1 channel. The peak is broadened due to the channel delay spread.

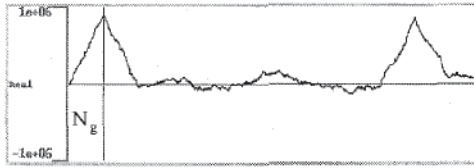


Figure 10 2K-OFDM: $N_t = N_g = 256$, $C/N = 3\text{dB}$

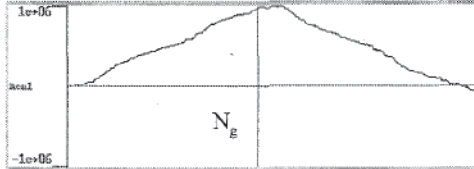
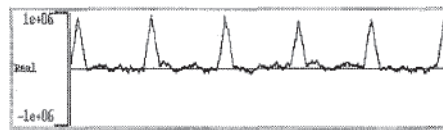


Figure 11 2K-OFDM: $N_t = N_g = 256$, after P1 channel (detail of the peak)

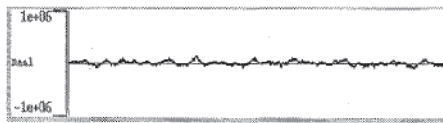
If the number of sub-carriers N used in the correlation is different from the actual one in the transmitter, no peaks will appear (Figure 12).



(a) correlation with $N=2K$



(b) correlation with $N=8K$



(c) correlation with $N=1K$

Figure 12 correlation of 2K-OFDM with different values of N

In order to decide how many sub-carriers are being used, two correlations are calculated during several symbols with the two possible N values and N_t equal to the minimum N_g expected. The maximum values are compared and if they exceed a certain threshold, the N value which produced the highest maximum is chosen.

The Guard Time is estimated by finding four consecutive peaks in the correlation calculated with the just estimated N value and N_t equal to the minimum N_g expected for this N value. The distance between the first and the fourth peak indicates the N_g value:

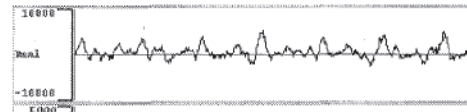
$$N_g = (\max_4 - \max_1 - 3N) / 3$$

Once that N and N_g are known, a last correlation is calculated with these parameters, and the FFT starting

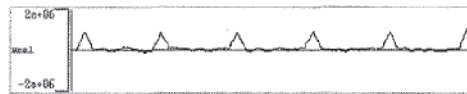
point is given by the peak position. A finer adjust can be achieved later by controlling the A/D converter clock.

The precise synchronization in the receiver depends strongly on the alteration of the correlation properties caused by the presence of noise and multipath. If the peaks can not be clearly identified or their position changes, the synchronization will fail.

Figure 13 shows that the correlation in an OFDM system with 128 sub-carriers is much more sensible to AWGN than a 2K one. Since the difference between the peaks and the correlation floor is much lower in the first one, the noise level can hide the peaks.



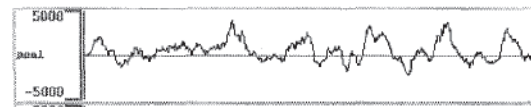
(a) 128-OFDM with $C/N=3\text{dB}$



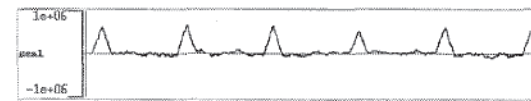
(b) 2K-OFDM with $C/N=3\text{dB}$

Figure 13 correlation sensitivity to AWGN

The sensitivity to multipath delay spread is also higher in a 128 sub-carrier system. In Figure 14, 2K and 128 are compared when using the same N_g/N value, showing that multiple peaks are generated in the 128 system.



(a) 128-OFDM with $N_g=16$



(b) 2K-OFDM with $N_g=256$

Figure 14 correlation sensitivity to multipath

For these reasons, synchronization of a system with a low number of sub-carriers using the OFDM correlation is more a difficult task.

3.4 Non-linear effects in OFDM

Efficient use of power amplifiers implies a working point close to saturation, which causes a non-linear behavior and thus a degradation in the signal quality.

Since the OFDM signal is composed of many independently modulated sub-carriers, it presents a Gaussian distribution (Central Limit Theorem) with high peak to medium value ratios. This fact makes it

very sensitive to non-linear effects.

Provided that it is big enough to satisfy this theorem ($N > 100$), the number of sub-carriers does not affect the peak to medium value ratio. In fact, simulated OFDM signals (1500 symbols) exhibit a 12.9 dB variation when the modulation is QPSK and 13.2 dB when it is 16-QAM, independently of the value of N (128, 2K, 8K).

The error performance degradation caused by a non-linear amplifier has been studied via simulation, using complex envelope representation and the AM/AM characteristics of the amplifier. The results are presented in Figure 15 and Figure 16 for 2K and 8K systems.

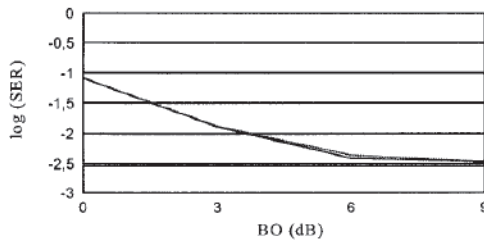


Figure 15 performance of 16-QAM-OFDM

A back off of 6 dB is needed to demodulate a 16-QAM signal with a degradation in $\log(\text{SER})$ of only 0.13 with respect to an ideal situation for a C/N ratio of 16 dB.

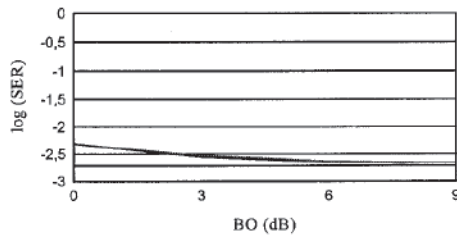


Figure 16 performance of QPSK-OFDM

When the modulation is QPSK and $C/N=9\text{dB}$, a 3 dB back off is enough, with a degradation of 0.16 in $\log(\text{SER})$.

In both cases, the number of sub-carriers does not affect the error performance.

3.5 Reduction of the number of sub-carriers in an OFDM system

To summarize, the conclusions of the preceding sections are:

a) Simulations show that large Time Guard intervals are needed to fight inter-symbol interference (ISI) caused by multipath. For this reason, in order to maintain a reasonable information rate, a system with a low number of sub-carriers should be avoided.

When ISI is conveniently suppressed, the channel frequency response has to be estimated in order to correct the amplitude and phase variations caused to the signal. If pilot-based interpolation is used, a number of sub-carriers are needed to accommodate enough pilots

for the estimation. This means that again 128 sub-carriers are not sufficient to provide a SER improvement.

b) Depending on the phase noise bandwidth expected in the system, two situations can be observed:

- given that phase noise variations are not very fast related to the OFDM signal, a greater number of sub-carriers will lead to a worse performance.

- if $T_\phi < T_{\text{OFDM}}$, the same performance is achieved regardless to the sub-carrier spacing.

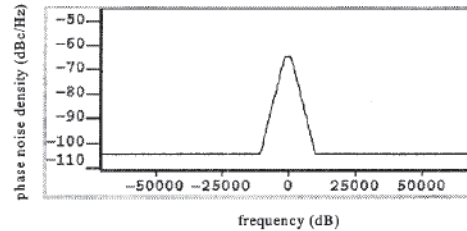


Figure 17 dTTb phase noise mask

In situations when phase noise bandwidth is less than 71 KHz, the error performance of a system with 128 sub-carriers will be better than that of a system using 2K or 8K. This will be normally the case in the system under study, as it can be deduced from the phase noise mask defined within the dTTb project (Figure 17).

c) Synchronization functions are harder in a 128 sub-carrier system, because the correlation used for this purpose is much more sensitive to AWGN and multipath.

d) OFDM signals constrain the power amplifiers back off to be higher than in single carrier applications. However, the non-linear effects do not depend on the number of sub-carriers used, given that the number is greater than 100.

These points imply that a prototype with 128 sub-carriers will not provide the same information as a 2K or 8K one about the main impairments which affect the OFDM signal and as a consequence, the first solution suggested to the real-time Rapid Prototyping of this system would not be acceptable.

4. NON REAL TIME IMPLEMENTATION OF THE WHOLE SYSTEM

The following process has been carried out to obtain a prototype of the whole system:

① Simulation models for the basic elements in transmitter and receiver

- Inner coding: convolutional codes with different coding rates obtained by puncturing of the mother $\frac{1}{2}$ code [8,9]. They are decoded using the Viterbi algorithm with the same decoder to every punctured code and a previous insertion of dummy bits.

- Inner interleaving specified in dTTb.

- Digital modulation: multi-resolution [7] 4, 8 or 16-QAM combined with inner coding.

- OFDM-OFDD [22] with 2K and 8K sub-carriers using frequency guards as a protection against adjacent channel interference (ACI) and time guards to fight inter-symbol interference (ISI).

② Simulation model for the channels. Channel estimation and synchronization

Two channel models have been implemented for simulation, which correspond to those suggested within the dTTb project to evaluate the system performance: F1 for fixed reception and P1 for portable reception [5,26].

Pilot sub-carriers have been introduced in the OFDM frame and channel correction by interpolation of the channel response (section 3.1) has been studied and optimized [5,26].

Simulation models for synchronization of the receiver using the OFDM correlation properties have been created.

③ DSP implementation of the basic elements in transmitter and receiver

After optimization of the above described transmitter and receiver basic functions, C code has been generated to be compiled and executed in an Ariel MM-96 board [23] containing two Motorola DSP96002 [24].

Simulated and DSP signals have been compared to check the correctness of the prototype and verify the achievement of the system specifications. Modulation and coding parameters have been optimized in a feedback process between simulation and DSP prototype.

④ DSP implementation of the channel estimation and synchronization subsystems

In the same way C code has been generated and verified for the channel estimation (and correction) and synchronization subsystems.

The transmitter runs in an MM-96 Ariel board [23]. It reads MPEG2 data from a file (or any general data type), processes the base band signal (coding, digital modulation and OFDM) and writes the signal back to a file.

The receiver, in another MM-96, reads this file (which can be modified in the simulator to include signal distortions such as multipath or phase noise), realizes the synchronization process and then obtains the output data after channel correction, demodulation and decoding.

In this case, Rapid Prototyping can offer some advantages even though the prototype can not run in real time. It is possible to optimize parameters and verify the possibility of implementation. Besides, subjective qualities can be observed, since MPEG2 images obtained in the receiver after channel impairments can be compared to the transmitted ones.

5. CONCLUSIONS

There is an increasing interest in Rapid Prototyping of communications systems, with the main objective of reducing the design cycle and improving the products quality. However, Rapid Prototyping of a complex system presents some difficulties, which depend on the system characteristics.

We have applied this concepts to the construction of a prototype for the European Digital Television for Terrestrial Broadcasting System (dTTb) whose transmission technique (Orthogonal Frequency Division Multiplexing) has been introduced. After identifying the problems associated with the construction of a prototype, two different solutions have been proposed and discussed:

- Scaling the number of sub-carriers in the OFDM system so that a real time implementation is possible.

- Non real time implementation of the whole system.

The first solution has been discarded, since a scaled system would not provide the same information about the main signal impairments as the real one.

The second solution has been adopted, and a prototype has been presented which allows us to optimize parameters, verify the possibility of implementation and observe subjective qualities.

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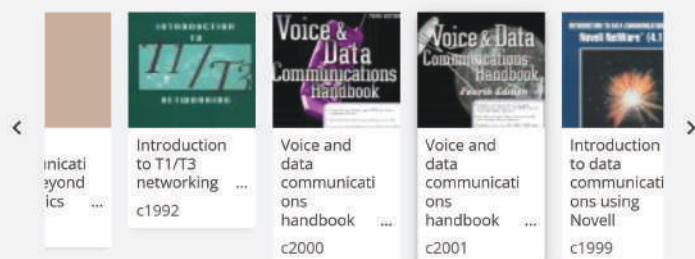
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ACKNOWLEDGMENTS

Well, here I am again, finalizing the latest book for McGraw-Hill. This one is special because it is the fourth edition of the *Voice and Data Communications Handbook*! The original book came out in 1995 but has blossomed quite a bit since then. It is hard to believe that so much has happened over these few years.

This book deals with the issues surrounding the telecommunications industry on voice and data topics as the two converge. As always, I chose to write the way I think, that is, in a non-technical fashion. I hope that this is consistent with you, the reader, because there is little published that is geared for the novice and business professional. Besides the new chapters, we added something new this time in response to many professors around the country. In the beginning of each chapter, we have an objectives section and at the end of the chapter we have added some questions. We hope this adds and rounds off the information based on this new information. We can thank the educators for their interest and requests.

To be fair about this production, we owe a lot of credit to many people. Some of the people interacted with us regularly, and others only occasionally. First, we must thank Steve Elliot, McGraw-Hill's executive editor on this book, who prodded me to keep going. In addition to Steve is Alex Corona who e-mailed us weekly, keeping the project on schedule.

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Two people in my office deserve the lion's share of the credits for the ultimate graphical representation and production of this book. The first is Gabriele my wife and partner of more than three decades. She is the silent contributor of this production. Gabriele really deserves to have her name on the cover of this book. Second is a young lady whose energy and enthusiasm never seem to cease. Amber Hartmann and Gabriele worked dauntlessly to keep the graphics accurate and readable, while at the same time creating interesting renderings. Amber's age belies her maturity and

ability to jump right in and get things done quickly, even though we change them constantly.

This team of people all pulled together to make this fourth edition of the *Voice and Data Communications Handbook* a reality. They deserve the credit.

Finally, I want to thank you the reader for giving up your time to read this book. I receive many calls and e-mails from readers who just want to let me know that they enjoyed my opinion or the way I present an idea. I hope I can continue to win your support. My best wishes to you all!

Thank you all,

Regis J. (Bud) Bates

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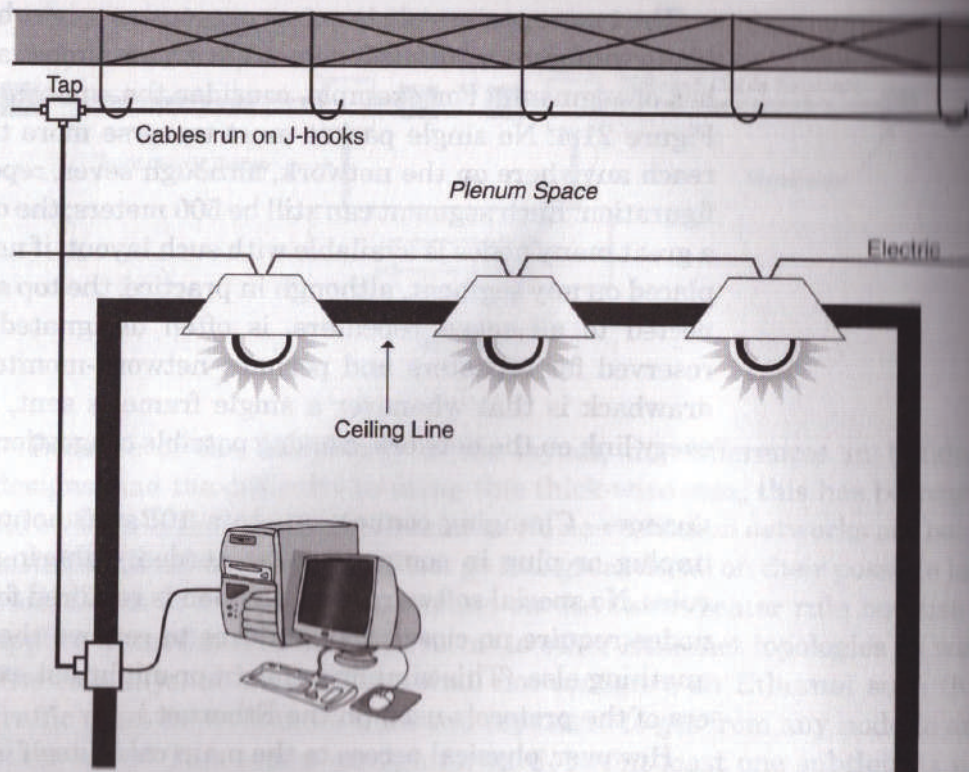
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Figure 21-5

To move a station is very complex. It requires going above the ceiling. The drop behind the wall may not lend itself to removal.



quite an effort. For this reason and others, 10Base5 is rarely installed anymore. Figure 21-5 shows how accessing the cable and the need to add a drop cable from the ceiling to the device can be problematic.

10Base2

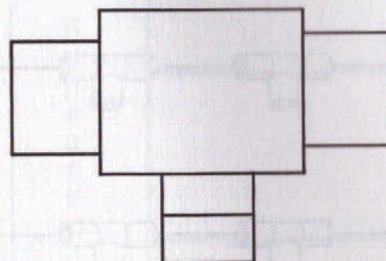
10Base5 wiring is extremely difficult to work with and costly on a per-foot basis. With improving technology, companies determined that by applying some engineering smarts, they could design a new Ethernet standard (still 802.3) for use on a much lighter, flexible, and less expensive type of coaxial cable. 10Base2, also often referred to as thin wire or cheapernet, is specified to run on RG-58A coaxial cable. This cable is almost identical to cable that you probably have running into your home for cable television. However, the configuration of 10Base5 and that of 10Base2 have quite a number of differences.

10Base2 Piece Parts As with the other 802.3 media, 10Base2 requires a network interface card (NIC) in each node. However, the NIC is much smarter and the tap is much simpler (and less expensive) than in a 10Base5 configuration. Also, no transceiver cable is required or even allowed; instead, the tap, called a *T connector*, plugs right into the back of the NIC. The T connector splits the signal on the cable, enabling it to continue on and also sending a copy directly into the connector on the NIC—a coax connector of the same type as on the other two sides of the T connector. A T connector looks something like the example shown in Figure 21-6.

T connectors have advantages and disadvantages compared to transceivers. They are far less expensive, about one-tenth the cost. They can be added or removed from a 10Base2 daisy chain in seconds, much more quickly than a 10Base5 transceiver. However, unlike with 10Base5, T connectors are inserted in line in the coaxial cable; if a T connector is to be added or removed, the entire cable will be down for a few seconds while the change is being made. This is true even if the T connector is being added to the end of the cable. Once a T connector is added to the cable, unplugging it from or plugging it into its attached node does not disrupt the cable so long as the T connector itself remains in the cable. For this reason, many installations preconfigure many T connectors in each daisy chain to avoid later disruption.

The minimum distance between T connectors is 0.5 meters (1.6 feet). One 10Base2 segment can be up to 185 meters (607 feet) long, much shorter than a 10Base5 segment. As with 10Base5, every segment must end with a terminator, in this case one designed for 10Base2. As you can see in the next section, how the coax is terminated and how it is laid out are different when compared with 10Base5.

Figure 21-6
The 10Base2 T
connector



Configuration of 10Base2 Parts

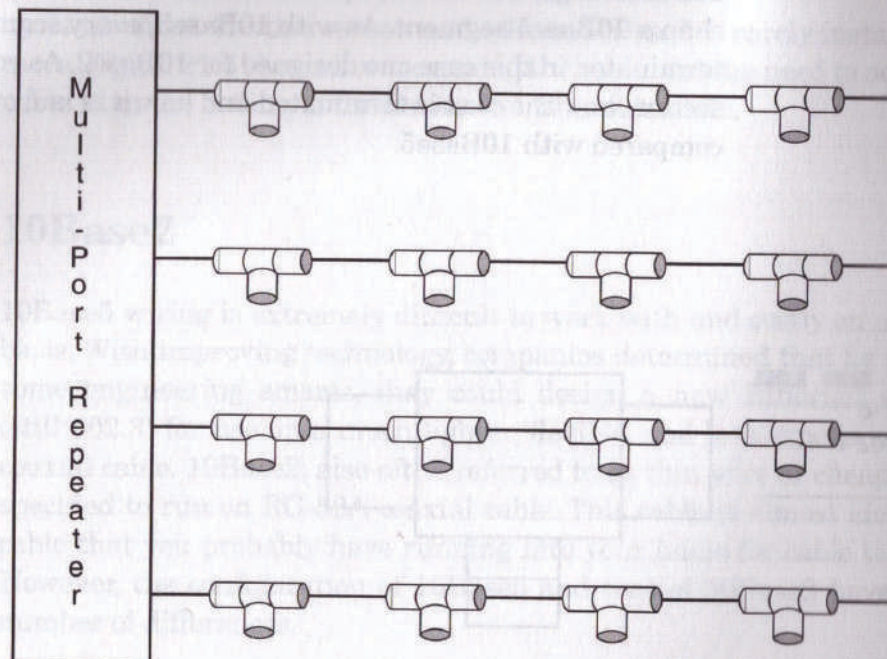
Setup 10Base2 is supported in two different kinds of configurations and is also often used in a third configuration not originally envisioned in the specification. The three configurations can briefly be summarized as follows:

- Star with daisy chains
- Pure star configuration
- Daisy chain bus

The original specification for 10Base2 was a star configuration, with each radiating spoke as a daisy chain bus. Such a configuration might look like the example in Figure 21-7.

A *multiport repeater* (MPR) takes every signal it receives on one daisy chain and sends it out over all of the other daisy chains to which it is connected. Up to 27 T connectors (some vendors support up to 30) can be installed on each daisy chain; the number of ports on the MPR limits the number of daisy chains. The last T connector on each daisy chain must have a terminator on one side. The MPR is an active device; it plugs into AC power. As such, it is grounded through its power cord and therefore provides an electrical ground for each attached segment. Thus, no separate ground is

Figure 21-7
10Base2 using a
multiport repeater



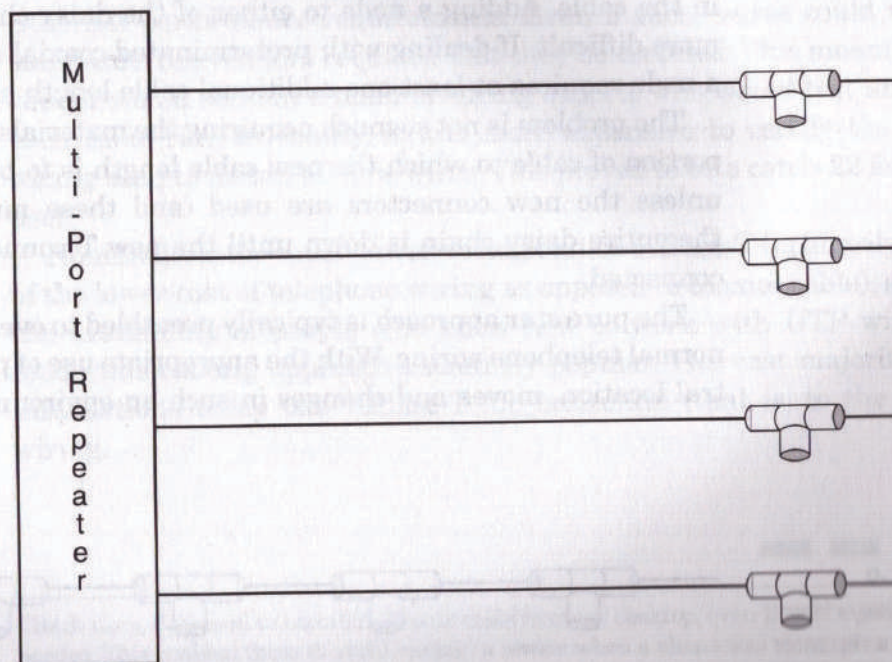
required (or indeed allowed) for the individual segments. Note that each daisy chain is plugged directly into a port on the MPR; the cable end at the MPR does not require a T connector.

This MPR configuration of daisy chains is very cost-effective compared to 10Base5. However, wiring and maintaining it is rather onerous. Until the last few years, using this approach for wall-plate installations (vs. just running the cable along the floor) was very difficult and often subject to frequent outages as individuals interrupted connections, disrupting the entire daisy chain. More recently, special wall plates have come onto the market that simplify such wiring; however, they are quite expensive. 10Base2 installations can also use a pure star configuration, as shown in Figure 21-8.

With only one T connector (and therefore only one Ethernet node) per cable, the per-port cost of a 10Base2 pure star is much higher than the daisy chain approach; the cost of the MPR itself is spread across far fewer devices than with the previous configuration. Nonetheless, the star has two major advantages over both the daisy chain and 10Base5:

- Because it is no longer a physical bus (although it is still a logical bus), it can use the physical communications paths installed in buildings for

Figure 21-8
10Base2 pure star



the purposes of telephone wiring because telephone wiring is also star configured.

- Because each node is on its own cable, cable faults generally do not affect other nodes through the MPR.

Vendors officially support both of the two previous 10Base2 configurations. However, vendors do not support the following configuration. The pure daisy chain bus (Figure 21-9), without use of any repeater, was not contemplated by the specifiers of the 10Base2 standard (perhaps because the opportunity to sell equipment to implement it is minimal). The biggest problem with it is that, although every Ethernet segment is supposed to be grounded, daisy chains without repeaters usually are not grounded in practice.

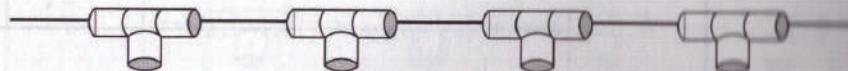
Because such networks are by definition very small (not to exceed 30 T connectors), the problems brought on by grounding them improperly usually do not cause major interruptions. Certainly, this is probably the least expensive type of Ethernet configuration on a per-port basis that supports more than two nodes. All of the cabling components together (except the NICs and software) can be assembled for about \$10 to \$25 per Ethernet node total in most cases.

Changes Removing a node from any 10Base2 network is simple; just unplug the T connector from the back of the NIC, leaving the T connector in the cable. Adding a node to either of the daisy chain configurations is more difficult. If dealing with preterminated coaxial cable lengths, adding a node requires at least one additional cable length and a T connector.

The problem is not so much acquiring the materials as it is getting at the portion of cable to which the new cable length is to be added. In addition, unless the new connectors are used (and these must be preinstalled), the entire daisy chain is down until the new T connector is inserted and connected.

The pure star approach is typically precabled to every work location, like normal telephone wiring. With the appropriate use of patch panels at a central location, moves and changes in such an environment are easier than

Figure 21-9
10Base2 daisy chain
bus without repeater



moving telephones. (Normally, telephone moves involve telephone number changes; Ethernet moves require only connecting the new location up to any active MPR port.) Locations not requiring Ethernet connectivity do not have their coaxial cable runs connected to an active MPR port. If 10Base-T wiring had not been invented, the 10Base2 approach might have become much more popular.

10Base-T

10Base-T defines a standard for running Ethernet over unshielded twisted pair (UTP) wiring. The prospect of using existing, in-place (but unused) telephone wiring provided much of the impetus for the development of this standard. Many organizations had already been using some of the existing wiring in their buildings after the breakup of the Bell System in 1984. What actually happened was that Bell came along and told users that the in-house (station) wiring was theirs. Bell would no longer be in the in-house wiring business and would not maintain the wires as they had in the past. Realizing that the number of wires in the building just for the telephone systems was extraordinary² and that installing new wiring was expensive, many organizations saw the opportunity to use the existing spare telephone wires to run their higher-speed LAN connections. However, in practice, little of the wiring that was in place (when the standard came out) could meet Ethernet performance requirements. Even if these wires could meet the standards, the vendors required that they be certified. This meant that the vendor would send in a team of wiring experts who would test and certify each cable run. In reality, it was more expensive to certify the existing wiring than to install all new wires. This proved to be a catch-22 for the end user.

Nonetheless, the much lower wiring cost of 10Base-T (primarily because of the lower cost of telephone wiring as opposed to coaxial cable), as well as the availability of people who know how to work with UTP wiring, has made this cabling approach extremely popular. The vast majority of new installations today use 10Base-T for horizontal (that is, to the desktop) wiring.

² Back then, Bell used to install a 25-pair cable to every desktop, even if only a single pair was needed. This enabled them to avoid having to rewire when a phone was changed or moved.