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UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA, SAN JOSE DIVISION

APPLE INC., a California corporation,

Plaintiff,

vs.

SAMSUNG ELECTRONICS CO., LTD., a Korean business entity; SAMSUNG ELECTRONICS AMERICA, INC., a New York corporation; SAMSUNG TELECOMMUNICATIONS AMERICA, LLC, a Delaware limited liability company,

Defendant.

CASE NO. 11-cv-01846-LHK

DECLARATION OF TODD M. BRIGGS IN SUPPORT OF SAMSUNG'S OPENING CLAIM CONSTRUCTION BRIEF

Date: January 20, 2012
Time: 10:00 am
Place: Courtroom 8, 4th Floor
Judge: Hon. Lucy H. Koh

SUBMITTED UNDER SEAL

I, Todd M. Briggs, declare as follows:

1. I am an associate with the law firm of Quinn Emanuel Urquhart & Sullivan LLP and counsel for defendants and counter-claimants Samsung Electronics Co. Ltd., Samsung Electronics America, Inc., and Samsung Telecommunications America, LLC (collectively, "Samsung"). I submit this declaration in support of Samsung's Opening Claim Construction Brief. I am personally familiar with and knowledgeable about the facts stated in this declaration and if called upon could and would testify competently as to the statements made herein.

2. Attached hereto as **Exhibit A** is a true and correct copy of certain excerpts from the Deposition of Hun-Kee Kim, Rough Transcript, dated November 30, 2011.

3. Attached hereto as **Exhibit B** is a true and correct copy of SAMNDCA0013600, an online article from Yonhap News describing the selection of SMP technology by the 3GPP standards setting body. Also attached is a certified translation from Korean to English.

4. Attached hereto as **Exhibit C** is a true and correct copy of "Samsung Electronics' Asynchronous IMT-2000 Technology Adopted as International Standard Specification," September 20, 2002, an online news article from iNews24.com. Also attached is a certified translation from Korean to English.

5. Attached hereto as **Exhibit D** is a true and correct copy of certain excerpts from the Deposition of Richard D. Gitlin, dated December 6, 2011.

6. Attached hereto as **Exhibit E** is a true and correct copy of certain excerpts of Gitlin, Hayes and Weinstein, DATA COMMUNICATIONS PRINCIPLES, Kluwer Academic/Plenum Publishers (1992).

7. Attached hereto as **Exhibit F** is a true and correct copy of certain excerpts from the Deposition of Tony Givargis, dated December 6, 2011.

8. Attached hereto as **Exhibit G** is a true and correct copy of U.S. Patent No. 7,200,792.

9. Attached hereto as **Exhibit H** is a true and correct copy of U.S. Patent No. 7,698,711.

10. Attached hereto as **Exhibit I** is a true and correct copy of certain excerpts from U.S. Patent Application No. 11/778,466.

I hereby declare under penalty of perjury under the laws of the United States that the foregoing is true and correct.

DATED: December 8, 2011

QUINN EMANUEL URQUHART & SULLIVAN, LLP

By */s/ Todd M. Briggs*
Todd M. Briggs
Attorneys for Defendants/Counter-Claimants SAMSUNG ELECTRONICS CO., LTD., SAMSUNG ELECTRONICS AMERICA, INC. and SAMSUNG TELECOMMUNICATIONS AMERICA, LLC

Exhibit A
FILED
UNDER SEAL

Exhibit B

삼성전자 IMT-2000 비동기기술 국제표준 채택

(서울=연합뉴스) 김범수기자= 삼성전자는 최근 세계 정보통신기술협회(TTA)주관으로 신라호텔에서 열린 3GPP(3세대 프로젝트그룹)회의에서 자체개발한 IMT-2000비동기 접속방식인 `SMP'기술이 국제 표준기술로 채택됐다고 20일 밝혔다.

삼성전자의 SMP(Symbol Mapping based on Priority)는 잡음에 의한 오차를 최소화해 고속 데이터 전송을 구현하는 기술이다.

삼성전자는 'IMT-2000기술의 표준화 과정에서 퀄컴, 노키아 등과 함께 선두그룹에 속하게 됐다'며 '차세대 이동통신 사업선정에 유리한 고지를 확보하게 됐다'고 설명했다.

bumsoo@yna.co.kr (끝)

2002/03/20 11:00 송고

◀이전화면 | 프린트서비스

CERTIFICATION OF TRANSLATION

I certify that the Korean to English translation of the Korean internet newspaper article entitled ***SAMNDCA00146000*** is an accurate and complete rendering of the contents of the source document to the best of my knowledge and ability. I further certify that I am a qualified professional translator familiar with both languages with more than ten years of experience in Korean to English translation of various legal, technical or business documents including a number of legal evidentiary documents submitted to various courts in the United States.

Date: December 6, 2011

____

Alex N. Jo, Translator

Samsung Electronics'IMT-2000 Asynchronous Technology Adopted as International Standard

(Seoul = Associated Press) Reported by Bum Soo Kim = Samsung Electronics announced on March 20 that its 'SMP' technology, which is an IMT-2000 asynchronous connectivity mode developed in-house, was adopted as the international standard technology at the 3GPP (3^{rd} Generation Project Group) meeting recently held by the International Telecommunication Technology Association (TTA) at Shilla Hotel.

Samsung Electronics' SMP (Symbol Mapping based on Priority) is a technology that minimizes error caused by noise. Thus enabling implementation of high-speed data transmission.

Samsung Electronics said, "In the course of IMT-2000 standardization process, we have emerged as a leader group company along with some other companies such as Qualcomm and Nokia, which enables us to preemptively secure an advantageous position in the next generation mobile communications business."

bumsoo@yna.co.kr (The End)

Sent on March 20, 2002 11:00

Exhibit C

삼성전자의 비동기 IMT-2000 기술, 국제표준 규격으로 채택

2002.03.20일수 15:32 입력

삼성전자의 'SMP(Symbol Mapping based on Priority)'기술이 곧 국제통신연맹(ITU)의 국제 표준 규격으로 정식 채택될 예정이다.

삼성전자는 지난주 신라호텔에서 세계 20여개국 400여명의 정보통신 기술 관계자가 참석한 가운데 정보통신기술협회(TTA) 주관으로 열린 '3세대 프로젝트그룹(3GPP)'회의에서 삼성전자의 'SMP'기술이 국제 IMT-2000 비동기식 기술규격 표준으로 최종 채택돼 국제 표준기술이 됐다고 20일 발표했다.

이번에 국제 표준이 된 삼성전자의 'SMP'기술은 잡음에 의한 오차를 최소화함으로써 고속 데이터 전송이 가능한 기술로, IMT-2000 비동기 방식의 핵심기술이다. 이동통신 시스템과 단말기간의 통화 및 데이터 전송시 잡음을 줄임으로써 통신 품질을 향상시킬 뿐 아니라 더 많은 가입자들이 동시에 사용할 수 있다는 것.

삼성전자 관계자는 "삼성의 SMP기술은 신뢰도가 각기 다른 정보비트간의 상관관계를 분석해 정보비트는 신뢰도가 높은 위치로 배열시키고 잉여비트는 상대적으로 신뢰도가 낮은 위치에 배열시키는 방법으로 데이터 패킷의 전송 오류를 줄이는 기능을 한다"고 밝혔다.

한편, 삼성은 IMT-2000표준화 과정에서 다수의 표준을 확보함으로써 퀄컴, 노키아 등과 함께 선두그룹의 위치에 올랐다.

삼성전자는 "국제 표준으로 채택된 기술력을 바탕으로 차세대 이동통신 사업에 유리한 고지를 확보하게 됐을 뿐 아니라 상당한 기술 수입효과도 거둘 수 있을 것으로 기대한다"고 설명했다.

윤휘종기자 hwiparam@inews24.com

TAG 미투 0 댓글쓰기 뉴스정정요청

IT정책 컴퓨팅 통신·미디어 과학 글로벌 디지털기기 기업 자동차 금융 유통 경제일반 정치 사회 문화 생활

오늘의 주요 뉴스

홈 | IT/시사 | 연예/스포츠 | 엠톡 | 게임 | 오피니언

- 한나라당, '홍준표 체제' 당분간 유지
- 김진표 "종편 출범, 그들만의 잔치될 것"
- 410g 초경량…에이서, 태블릿 무게 종결자 출시
- 박주영 '68분 출전'…아스널 8강서 무릎
- 김동률 "이승환 '다만', 사랑 고백 위해 만든 곡"

통신·미디어 최신뉴스

더보기

- NHN '네이버 툴바'에서 메모·공유 기능 활용 하…
- 오버추어코리아, 11번가 검색광고 재계약 체결
- 네이버재팬 모바일메신저 '라인' 상승세 탔다
- 한컴 '씽크프리 모바일', 방통위원장상 수상

칼럼/연재

- [정기수]"맹장수술 900만원?" 한미F…
- [김영리]'반칙' 잦은 소셜커머스, …
- [박재덕의 턴]'강용석 해프닝' 일단…
- [박계현]넥슨 해킹사고와 '두마리토…
- [KISTI의 과학향기]삼각팬티도 특허…

프리미엄/정보

- [11. 29]세계 스마트폰 시장 지형도…
- [통계뉴스] 징가 소셜게임 '캐슬빌' …
- [11. 28]미국 블랙프라이데이 '엄청…
- [통계뉴스] 미국 이동통신 시장 현황
- [11. 24]그림으로 보는 삼성 vs 애플…

한국콘텐츠진흥원

[Ãâµ¿Æ¯º¯'ë]ÃßÃ¾ÌÀÇ µâ¶ó¸¶, ÀÌÁ¦´…
[,,È¾Ö´Í][ÄÜÅÙÃ÷ Á÷¾÷ Á¾'æ±â] …
[,,È¾Ö´Í]¶§·Ð ¾Æ'« »ý°¢¾øÀÌ ¾Ö´Í¸Þ…

Poll

애플의 혁신을 이끌었던 스티브 잡스가 세상을 떠났습니다. 이에 따라 잡스 없는 애플이 IT 시장의 주도권을 계속 잡을 수 있을지에 관심이 쏠리고 있습니다. 여러분들은 어떻게 생각하십니까?

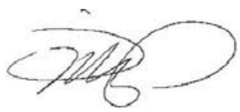
투표하기

등록번호 : 서울아00107 · 등록연월일 : 2005년 4월 6일 · 발행인 / 편집인 : 이창호 · 서울시 마포구 상수동 141-1 BR엘리텔 B동 3~4층 · 대표전화 : (02)3347-114
사업자 등록번호 : 120-81-97512 · 통신판매업 신고 : 강남-1298호 · 개인정보관리 책임자 : 김윤경

CERTIFICATION OF TRANSLATION

I certify that the Korean to English translation of the Korean internet newspaper article entitled ***news-inews24-com*** is an accurate and complete rendering of the contents of the source document to the best of my knowledge and ability. I further certify that I am a qualified professional translator familiar with both languages with more than ten years of experience in Korean to English translation of various legal, technical or business documents including a number of legal evidentiary documents submitted to various courts in the United States.

Date: December 6, 2011



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Alex N. Jo, Translator

Samsung Electronics' Asynchronous IMT-2000 Technology Adopted as International Standard Specification

Entered at15:32, September 20, 2002

[Exclusive] Developed a solar power Smartphone battery that "lasts 15 days with 1-time charge"

Soon, Samsung Electronics'SMP (Symbol Mapping based on Priority) technology is slated to be formally adopted as an international standard specification of the International Telecommunication Union (ITU).

The Telecommunications Technology Association (TTA) held a '3rd Generation Project Group (3GPP)' meeting at Shilla Hotel last week with about 400 attendees in the field of information communications technology from 20 or so countries. Samsung Electronics announced on March 20 that its own 'SMP' technology became an international standard technology after it was finally selected as a standard specification for the IMT-2000 asynchronous technology at the meeting.

Samsung Electronics''SMP' technology which just became the international standard is the technology that minimizes error caused by noise, thus enabling a high-speed data transmission. It is the core asynchronous technology in the IMT-2000. This technology improves communication quality by reducing noise during a telephone call between a mobile communications system and a user terminal as well as during data transmission, and also supports a greater number of concurrent users.

A person affiliated with Samsung Electronics says, "Samsung's SMP technology analyzes the correlation among the information bits with different degrees of reliability, thus arraying "information bits" in a position of higher reliability, and arraying "excess bits" in a position of lower reliability. This method plays a role of reducing data packet transmission error."

Meanwhile, with its numerous technologies adopted as standards in the course of IMT-2000 standardization, Samsung emerged as one of the leading [standards] companies along with some other companies such as Qualcomm and Nokia.

Samsung Electronics said, "We came to secure an advantageous position in the next generation mobile communications business based on our technological prowess selected as international standards. Also, we expect to gain considerable income associated with our technologies."

Reported by Hwi Jong Yoon hwiparam@inews24.com

Exhibit D

IN THE UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA
SAN JOSE DIVISION

APPLE INC., a California corporation,

Plaintiff,

vs.

Case No.: 11-cv-01846-LHK

SAMSUNG ELECTRONICS CO., LTD., a Korean business entity; SAMSUNG ELECTRONICS AMERICA, INC., a New York corporation; SAMSUNG TELECOMMUNICATIONS AMERICA, LLC, a Delaware limited liability company,

Defendants.
__________________________________/

VIDEOTAPED DEPOSITION OF RICHARD D. GITLIN, Sc.D.

Taken on Behalf of the Defendants

DATE TAKEN: Tuesday, December 6, 2011

TIME: 9:06 a.m. - 3:26 p.m.

PLACE: Embassy Suites Downtown Tampa
513 South Florida Avenue
Tampa, Florida

Stenographically Reported by:
Donna L. Peterson
Registered Diplomate Reporter
Certified Realtime Reporter
JOB NO: 44339

APPEARANCES:

Counsel for Plaintiff:

PETER J. KOLOVOS, ESQUIRE
WilmerHale
60 State Street
Boston, Massachusetts 02109

Counsel for Defendants:

TODD M. BRIGGS, ESQUIRE
Quinn Emanuel Urquhart & Sullivan
555 Twin Dolphin Drive
Redwood Shores, California 94065

Also Present:

Thomas Hallahan, videographer

P R O C E E D I N G S

THE VIDEOGRAPHER: Good morning, ladies and gentlemen. Today's date is Tuesday, December the 6th, 2011. The time is approximately 9:06 a.m. My name is Thomas Hallahan; I'm the videographer. The court reporter is Donna Peterson.

We are present at the Embassy Suites, 513 South Florida Avenue, Tampa, Florida. We're here for the purpose of taking the deposition of Dr. Richard D. Gitlin. The case is instituted in the United States District Court, Northern District of California, San Jose Division, case entitled Apple Incorporated versus Samsung Electronics Company, Limited, et al.

I will now ask the attorneys to introduce themselves, starting with the noticing attorney.

MR. BRIGGS: Todd Briggs from Quinn Emanuel for Samsung.

MR. KOLOVOS: Peter Kolovos of Wilmer Cutler Pickler Hale and Dorr for Apple.

THE VIDEOGRAPHER: Would the court please swear in the witness.

RICHARD D. GITLIN, Sc.D., called as a witness by the Defendants, having been first duly sworn, testified as follows:

THE WITNESS: Yes, I do.

DIRECT EXAMINATION

BY MR. BRIGGS:

Q. Good morning, Dr. Gitlin.

A. Good morning.

Q. Can you state your name for the record?

A. Richard Gitlin.

Q. And where do you live?

A. Just down the road in here, Tampa, 415 Knights Run Avenue, Tampa.

Q. Okay. How long have you lived in Tampa?

A. We've -- this is my fourth academic year. We also have a residence in New Jersey.

Q. How long did you live in New Jersey?

A. About 40 years.

Q. How many times have you been deposed?

A. As an expert or including as a fact witness?

Q. How about both.

A. Somewhere between 15 and 20.

Q. How many times as an expert witness?

A. This is probably about my 10th, 12th time.

Q. When was the most recent deposition you had?

A. I think this lady was handling my most recent one. That was in the spring of this year.

Q. Okay. And what case was that for?

respect to that HSDPA patent in the InterDigital versus Samsung case?

A. Similarly, that validity -- both sides, and infringement.

Q. So you wrote a report stating that or opining that Samsung infringed that HSDPA patent?

A. Yes.

Q. And you also wrote a report opining that that HSDA (sic) patent was valid?

A. Yes. There were, I mean, there were reports, plural. They were -- they went back and forth in this, with supplementary reports and -- in that case. And then the cases were -- you know, the first case was part -- was -- everything I did in the first case was part of the second case. So by the end, I think I had seven or eight reports that I was the author of.

Q. Do you -- do you remember the number of the patent in that case, that you were working on?

A. I -- I don't want to guess. No.

Q. Okay.

A. I'm sure you could find it out.

Q. What did the technology in that case -- or in that patent involve, at a little bit lower level?

A. It dealt with the control channel for HSDPA.

I can tell you a little more if you --

Q. Yeah.

A. It dealt with a -- the patent dealt with a mechanism for signaling on the channel in a -- with a minimum use of bits. It was a clever way of doing this. In fact now, when I teach my wireless course, I use that as an example of a clever way to achieve a function.

Q. Now, is HSDPA part of any standards?

A. Yes.

Q. What -- what standard or standards?

A. Well, it's in the 3GPP family.

Q. Okay. Do you know if InterDigital believed that that patent was essential to the 3GPP standard?

MR. KOLOVOS: Objection.

A. I believe that the -- that that -- that would be a fair statement, yes.

Q. So do you know what it means for a patent to be essential to a standard?

A. I think I have a rough understanding, not a legal understanding, but a rough engineering understanding, an expert witness understanding.

Q. What's -- what's your understanding, you know, as an expert witness?

A. That to -- that to build a piece of equipment that's compliant with the standard, you necessarily infringe the patent.

Q. Now, in your expert report in that case, did you take that position that this patent was essential to the 3GPP standard?

A. Yes.

Q. Have you ever done any work for Samsung?

A. No.

Q. Other than this case, have you ever done any work for Apple?

A. No.

Q. So this is the first time you've been retained by Apple?

A. Yes.

Q. Has Apple retained you only in its lawsuit against Samsung, or are you also working in other cases Apple has?

A. As far as I know, this is what I'm doing for Apple.

Q. Have you ever done any work for HTC?

A. No.

Q. Okay. Have you ever done any work for Motorola?

A. No.

Q. Okay. Have you ever done any work for Google?

A. No.

Q. And you're not currently retained by Apple to input bits from some source. And the 120 is the channel encoder. Here it's a -- understood to be a turbo coder, or encoder. And it produces S bits, which are systematic bits, and P bits are the parity bits. And the S bits are the actual input to the channel encoder, the output of the CRC generator.

And the parity bits are generated by the shift registers inside the turbo encoder, shift registers and other elements. And the rate matcher is a -- is a device which will either puncture or eliminate bits or repeat bits to match the output rate to the available transmission capacity.

Bless you.

The -- so an interleaver is a common device in wireless systems because wireless -- most codes are designed to provide very good performance in random channel areas that are come -- that come randomly. Wireless systems have a different property. They have bursty errors. And they have bursty errors because when you're moving and you are in a fade, when you have, let's say, a low received signal level. So you're more likely to make errors in a bunch, in a burst.

And so an interleaver is a clever device that, for example -- it could be done many ways, but similar to what's described in the patent. You read bits into a -- you think of a matrix. You read bits into a row, and you read -- and you read them alpha transmission in a column. So, for example, if you had a burst where a whole column was errored, then viewed from the -- and it in the first column, then at the receiver viewed from the viewpoint of each row, you just have one bit in error, and the code will be able to correct that. That's the simple -- that's the very simple explanation. The interleavers in -- in the patent are much more sophisticated than that.

And then the -- and so the -- the notion of the interleaver is that from the viewpoint of the receiver, which is not shown in Figure 1 -- this is a transmitter -- is you -- you turn the phenomenon of a physically bursty error mechanism in a wireless channel to a -- as processed by the receiver, independent errors spread out over a long time. So the errors tend to be interleaved over time.

And so -- and the bit stream at the output of element 140 goes into a modulator. And I would call that a mapper, bit mapper. So that's -- in the three levels of modulation I described, this would be -- that's the first one. And I think that's a nonstandard use of the term. I'd -- I would say most people would call that a symbol mapper or a mapper, bit-to-symbol mapping.

And then the -- as I said, the controller is getting information as to the state of the channel and will adjust the level of encoding, let's say rate one-half, rate three-quarters, and/or the modulation of the symbols that you use, let's say a 16 QAM signal constellation or a 64 QAM signal constellation, depending upon the quality of the transmission channel.

Q. In -- in box 150, I -- I believe you just testified that a bit stream enters that box, which is labeled "Modulator."

A. Uh-huh.

Q. What is the output of the modulator?

A. So -- so the -- as it says in paragraph 28, the modulator can be either QPSK symbol, an 8PSK symbol, a 16 QAM symbol, or a 64 QAM symbol.

Q. So is that output, is that digital data, is it a bit stream, or is it an analog signal? What is it?

MR. KOLOVOS: Objection.

A. Each -- for example, if you're using choice three, 16 QAM, 4 bits come in. The output is a number. It can be an X and Y number. You can think of it as a vector in the X and Y plane. You can think of it as a two couple. It will have discrete values. The typical scaling labels will be, you choose, plus or minus 1, plus or minus 3. That could be volts, millivolts, microvolts, depending upon the transmitter power.

So you asked before: Is that digital? I say it's discrete valued. There is the 16 discrete points. You said one of those 16 discrete points.

Q. Now, are those values you were just talking about, are those used to modulate or alter a carrier wave?

A. If you recall my three levels of modulation, you -- what's not -- it's not shown -- the rest of the system is not shown here. But typically what you would do, you would take the -- let's take 16 QAM. You would take two of the bits, feed it to -- let's call it the inphase rail, and two of the bits to the quadrature rail. Then you would use pulse amplitude modulation, my second level of modulation, and you would -- so in that 16 QAM case, you would -- you would amplitude modulate a pulse with either a level a plus 1, minus 1, plus 3, minus 3. And you amplitude modulate a pulse, and this pulse will define the bandwidth of the signal. Typically these pulses belong to a family called raised cosine.

And so now what you've done -- and you do the similar mechanism for the quadrature channel, and you design what people in the art would call a "baseband bits are segmented at the input to the modulator at the -- let's say, if we look at case 16 QAM into 4 bit, you group 4 bits at a time, and that produces a symbol. That goes then to the second level of modulation, the third level of modulation. And you -- you -- generally this goes on for -- you know, you're sending lots of bits. You may -- it depends upon a particular system, and you're sending lots of bits, lots of symbols.

Q. Okay. So you said that the output of the mapper is a modulated pattern?

A. Yeah. That's -- that's Apple's construction. It's consistent with what's used in the -- as it says in -- on page 12, fifty -- paragraph 56, the independent claims 1 and 6 each recite the mapping, the collected bits from the first interleaver and second interleaver -- that's referring out to, I guess, not Figure 1, but it's the same idea -- onto one modulation symbol. That's what the patent describes it.

Q. So what is -- I'm trying to get an idea of what this modulated pattern is that you're talking about that is output from the mapper.

Is -- is this modulated pattern, are these -- is this a bit stream?

A. It's -- for 16 QAM, you would -- you could -- it -- now, it depends upon implementation, how you're going to implement it. But you -- you -- functionally or symbolically, you could think of it in the XY plane or IQ plane as a vector or a point. And that represents one of the 16 discrete constellation points associated with 16 QAM constellation. That's what the output is. And then you separately divide it, as I said, to get the level -- level 2 pulse amplitude modulation, which then leads to level 3 RF modulation.

Q. So in the case of 16 QAM, if you're looking at the constellation, would -- would you call one of the points in the constellation a modulated pattern?

A. That's -- well, that's a symbol. Yeah. That's what -- that's what Apple's construction is, and a -- using the language of the pattern -- of the patent. So you -- you typically, in a laboratory, would have that displayed. And you -- you would see various -- if you'd slow down time, you would see discretely points, one of those 16 points being illuminated. And that's a modulated pattern or a mapped pattern of bits.

So the symbol is a mapped pattern of bits. You map 4 bits into this XY two-topper or vector. That's what a symbol is.

Q. Okay. So when you use the term "pattern," that's referring to the pattern of bits that are input into the mapper?

A. Yes.
Q. Okay. That's where I was getting confused. I didn't -- I didn't understand what "pattern" meant in "modulated pattern."
So you're referring to, you know, in the case of 16 QAM, the 4 bits that are coming into the mapper, that would be the pattern that's modulated?
A. That would be the bit pattern, yeah.
Q. And so if a bit stream were going into a mapper, the first 4 bits would map to -- would be a pattern that maps to one symbol, the second 4 bits would be a pattern that maps to another symbol?
A. Well, it could be a very same symbol point. You got 16 points. If it's the same quartet of bits, it would map to the same point.
Q. Okay. Well, let's assume they're all unique.
A. Right. They can only be unique -- after -- after 16, you got to hit the same spot.
Q. But -- well, let's take an example where the bit stream is 12 bits and you have four unique quartets.
A. That's --
Q. Or three, three unique quartets.
A. Okay.
Q. So the first pattern would map to one symbol, the second pattern would map to a second symbol?

A. Yeah.
Q. And the third pattern would map to a third symbol?
A. Yeah.
Q. Now, why in -- in Figure 1 do you believe that the output is -- well, strike that.
Why do you believe in Figure 1 that the modulator does not include the pulse amplitude modulation or the RF modulation?
A. I was just looking at the abstract of the patent, but I'll -- I'll define the reference in the -- in the spec.
Well, if I look in column 2, I'm looking sort of, you know, starting at around 40 and ending at 53. You got to get down to the bottom. The -- "in order to adaptively select one of the modulation techniques according to the radio department."
I mean, there's no discussion of my second level of modulation. There's no, as far as I can tell, there's no pulse shaping involved. There's certainly no discussion of carrier frequency. But the -- certainly, since this is part of HSDPA, there is a standard. One could assume that.
So, I mean, I just -- that's all -- that's all that I see in the patent, and that's all that's -- are

modulator 280, in Figure 3, it outputs a modulated pattern?

A. One of 16 QAM points.

Q. Now, is the output of the modulator, is that 4 bits, or what -- what is the output?

A. It's -- it's a four -- it's a symbol that is one of the 16 points in the QAM, in the XY plane.

Q. But for it to appear like that, it has to go through the pulse -- the PAM and the RF modulation, correct?

A. No. You take -- you take 4 bits. You put it into a lookup table, and it gives you a complex number or an I and Q number. And you can just put that -- you can discuss that -- you can represent that in the signal constellation in the IQ plane or the XY plane as a signal point. It's understood. There's no figure of 16 QAM here, but.

Q. Okay. So going back to what a modulated pattern is, in the case of 16 QAM, you would -- you would say that a modulating -- a modulated pattern is one of the points in the constellation?

A. One of the 16 points.

Q. One of the 16 points in the constellation.

A. And there are various ways to represent that, as a two-topple XY pair, X coordinate and Y coordinate, or as a vector.

Q. So would you agree that you could also call that same point a "modulated signal"?

A. No.

Q. Why not?

A. Okay. To me -- and I see that Dr. Wessel uses that term -- a signal in general has a notion of bandwidth associated with it. That symbol coming out is a number. Numbers don't have bandwidth.

Now, as he points to my textbook, when you -- when you start out pedagogically and you're teaching students about statistical decision theory, you generally start with, are you sending signal one or signal two. So you're sending, let's say, 1 bit, one symbol, one signal. So in that pedagogical case, you can interchange the terms.

But in -- understanding of those skilled in the art, a particular symbol as I'm talking about is a number. It could be a complex number, I and Q. It's just a number. It doesn't -- you can't associate that -- people wouldn't call that "signal."

So what would people call a signal? People would call a signal, after you have a sequence of these symbols -- oh, let's say -- let's say -- let's say you wanted to send, in a real signal, just one -- in a real system, I want to get one symbol from me to you. So I take that one symbol. I pulse amplitude modulate it. Now it has a bandwidth. And I put it in an RF carrier and you receive it. So I've sent one symbol, but the signal is that composite where I can say it has -- exists for time and has a bandwidth.

A symbol is just a number. But in actuality, you send a plurality of such symbols in time, and the composite is called a signal.

Q. So I think you said something in your last answer. I thought you said a symbol is just a number?

A. Yes, I think that's what I said, a complex number.

Q. Okay.

A. Or an I and Q number, X and Y. That's -- that's how someone of ordinary skill would interpret that.

Q. And what would that number represent?

A. Well, it just -- in the language of the patent in the more generally, if a 16 QAM, it would -- it would have an association with 4 bits. You -- you tell me what symbol point, and I could tell you which 4 bits you're -- depends if you're the transmitter or the receiver -- what you're transmitting or what you believe you received. There's a one-to-one mapping.

Q. Now, you would agree that your textbook and other sources refer to symbols as signals?

A. Under -- as I -- as I said in my testimony which I just gave, that -- I believe the only time that I did that in my book would be in a pedagogical sense when you're sending one symbol. So therefore -- and it's pedagogical to teach students about statistical decision theory, hypothesis testing, maximum likelihood detection. So you're sending one signal, and there it's sending one symbol, and the terms are loosely used.

But no one of ordinary -- no one of skill in the art would say, "I give you a symbol, a 16 QAM symbol, a 64 -- a 64 QAM symbol," and say that's a signal. What's its bandwidth? How long does it last? I don't know.

Q. In your -- in your book or any other references outside of the patent that you've seen, have you ever seen a symbol referred to as a modulated pattern?

MR. KOLOVOS: Objection.

A. The -- certainly I don't think I used that in my book. I don't recall seeing any references. But this is consistent with, as I said, the unusual use of the term for element 280 as a modulator. I think most people would call that a mapper. And if you use the word "mapper," so that -- that would be a map pattern.

I think in my book I have the -- I did take a look. I use the word "pattern" for bit pattern. And I'm sure I used the word "mapper."

And it would be clear -- I mean -- you know, and also in these books -- mine is a graduate-level text when I was a faculty member. When I retired from Bell Labs in 2001, I taught at Columbia University for a couple years. So this was a Ph.D. level course. They still use my book. Now it's 20 years old. But, I mean, it -- this were is Ph.D. students. You didn't -- it wasn't necessary to define the term. You defined it used in the context.

Q. Have you ever seen in any extrinsic source or any source outside of the patent the output of a mapper being referred to as a modulated pattern?

A. Again, mapper. Well, if you -- if you have a mapper, you would say it's the -- it's the output of the mapper, you know. You have -- that's -- and most standards have, you know, a signal or mapping table.

Q. Okay. So I guess, in summary, you haven't seen any -- anything in the patent or anything in any other sources that describe a symbol as a modulated pattern?

MR. KOLOVOS: Objection; asked and answered.

A. Well, I disagree. I mean, as I said, if you look at Figure 3, the input is an input bit pattern, it goes to a modulator. So in plane English, that would be a modulated pattern at the output.

I think that the claim construction is informative more for "symbol" because that's the way it's used in the patent. In fact, if you didn't do it that way, you might be confused when you -- you could be confused when you read that term, because I would say, to turn it around like you were suggesting but which I disagreed with, that modulator could have all three levels of modulation, but clearly it only has the first level, and it uses it in an unconventional way. So I think it's wise that Apple use the language of the -- of the patent to clarify "symbol."

Q. Let me ask it one more time.

You have not seen anything, either in the patent or in any other sources, textbooks, treatises, papers, that describe a symbol as a modulated pattern, correct?

MR. KOLOVOS: Same objection.

A. I -- sitting here today, I can't recall the hundreds of thousands of papers that I've read, you know. We can put it into Google search. I -- I haven't done that in Google Scholar. So I can't -- you know, I'm not going to agree with you to that statement because, you know, my memory is not that good.

Q. But sitting here today, you can't identify the use of "symbol" in any of these -- in any source where "symbol" is defined as a modulated pattern?

MR. KOLOVOS: Same objection.

Q. Correct?

A. In any extrinsic? You know, I -- I -- I -- I think that's -- you know, you're entitled to ask the question. And I'd say I -- I -- I don't remember. I can't instantly search all the papers, hundreds, if not thousands, of papers in my 40-year career that I've read, things that I've written, you know.

It's just simply that the use of the word for element 280 modulator is, to me, nonstandard in mapping. So, you know, it's a symbol. A bit mapper would be pretty common as to what you're doing. You're mapping bits into a symbol. That's what that element 280 is doing in this special way in conformance with SMP.

Q. Okay. Let me -- let me try one more time.

Sitting here today, you cannot identify any source, any paper, treatise, book, anything that defines a symbol as a modulated pattern; isn't that correct?

MR. KOLOVOS: Objection.

A. I -- I haven't tried to. So, you know, if that was an exercise that I was asked to do, I would go about searching. But I haven't attempted that. So I'm not going to say it doesn't exist, but I haven't attempted to do that.

Q. But you would agree to me -- with me that sitting here today you cannot identify any book, treatise, paper, any source outside of the patent itself that defines "symbol" as a modulated pattern?

MR. KOLOVOS: Objection.

A. I'd just repeat my answer. I -- I haven't attempted to do that. So you're asking me to sort of reach a negative conclusion when I haven't attempted to do the work.

Q. So my question isn't -- it's not have you attempted to do it. I'm just saying that sitting here today you haven't identified in your declaration, and you can't identify -- sitting here, you can't identify any paper, book, treatise, any source that defines "symbol" as a modulated pattern, right?

MR. KOLOVOS: Objection.

A. I haven't been asked to do it, so I haven't done it. I haven't attempted to do it. I don't know the answer to the question.

Q. Okay. The next section --

MR. KOLOVOS: You want to break for lunch before we get to the next section?

MR. BRIGGS: Sure.

THE VIDEOGRAPHER: We're going off the video record. It's 12:35 p.m.

(Luncheon recess from 12:25 p.m. to 1:31 p.m.)

THE VIDEOGRAPHER: We're on the video record. It's 1:31 p.m.

BY MR. BRIGGS:

Q. Dr. Gitlin, Apple's construction of "symbol" has an interpretation of a modulated pattern in -- well, strike that.

Apple's construction requires a symbol to be in a sequence of such patterns. Do you see that?

A. Yes.

Q. Okay. Now, would you agree with me that a symbol does not necessarily need to be in a sequence of symbols?

A. Yes. You can send one symbol.

Q. Okay. So in defining "symbol," why do you think it's proper to require that the symbol appear in a sequence of symbols?

A. Well, I think it's -- it's informative because in these type of wireless and communication systems you generally send a sequence of symbols.

Q. But are you saying that the claim is actually limited to sending a sequence of symbols?

MR. KOLOVOS: Objection.

A. You mean claim 11?
Q. Yeah, claim 11.
A. Well, I mean, an apparatus for receiving data in the communication system comprising. So it would be understood of someone in skill in the art that a communication system, almost every system that I'm familiar with, sends a sequence of symbols.
Q. But other than your understanding of what somebody with skill in the art would believe, is there anything in the claim language that you can point to that requires a sequence of symbols to be sent?
A. Well, I think it -- for example, if you look -- it's understood from the spec. So if you look at Figure 5, for example. So look at the 64 QAM case, they show you five symbols. And --
Q. So that was Figure?
A. 5.
Q. 5. So it shows five symbols under 64 QAM?
A. Yeah. And it -- yes. And there's a reason for it, yeah, as I'm sure you're familiar with in the text. But it's illustrative that -- that you're going to -- generally -- in this case, it's to accommodate some limitation in memory. But you're -- you're going to have -- I think even in Figure 4 it shows for 64 QAM two symbols. But I think it's understood by -- when you say

I call level-one modulation, and can only talk about level-one, what it calls, demodulation. So I'll call it level-one mapping and level-one unmapping or demapping.

Q. Okay. So you're disagreeing with how the patent uses the terms "signal" and "symbol" here?

MR. KOLOVOS: Objection.

A. I'd like to read the patent in the column 21.

Q. Okay.

A. Yeah, I'm disagreeing. I mean, if I look at Figure 17, it -- it clearly shows that there's a signal sample coming in. And it's the -- the --

It's not clear at that point if the signal, the received signal sample, has been -- was -- has been resolved to one of 16 QAM points. You don't see that. So there is some ambiguity. But the demodulator is simply going from one of 16 -- it's a demapper -- one of 16 points to a 4-bit pattern. And then that 4-bit pattern has then split the stuff that's going to the systematic deinterleaver and the parity deinterleaver.

Q. Okay. So I -- I guess the answer to my question is, yes, you do disagree with how the patent describes the received signal as being a symbol?

MR. KOLOVOS: I object to the form. Mischaracterizes both his testimony and what the patent says.

A. So the -- at the receiver you -- you have a series of wave forms or samples, and those are proper to refer to that as "signal" or "signal samples." It's only, you know, when you're making a decision and saying, "Which of the 16 constellation points or symbols do you think has been transmitted," are you back into a symbol. So, you know, there is -- there is a -- it's never the case --

You're -- you're taking a received signal sample, and you're mapping it through -- through some decision device into one of these 16 points. Now you have a decision as to what you think the received -- what the symbol -- what you think what symbol was transmitted. And you go through this demodulator which is, I think, as I said, a poor choice of English, it would be a demapper.

Q. So can a symbol be transmitted?

MR. KOLOVOS: Objection.

A. A symbol going through the three steps of modulation. You -- you -- you generate a transmitted signal by following these three steps. You take a bit pattern; you map it, in the language of the patent; modulate it to a symbol. You amplitude modulate PAM, and then you RFO modulate it. And that whole composite is called a signal.

So yes, that's the way you transmit symbols or --

Q. Okay. So symbols are transmitted wirelessly?

A. Symbols are inside a -- if you look inside the airplane, there are symbols. If you look -- if you look -- if you look at the airplane, it's a signal. And what goes on the air is referred to as a signal.

Q. And the signal contains symbols, correct?

A. Yes.

Q. So symbols are transmitted in a signal, and symbols are received in a signal?

A. The receiver operation is more complicated. So you -- the patent doesn't describe any of the operations, other than these what I'll call demodulated -- it's called demodulating or demultiplexing.

And it -- so you receive a signal and you -- you undo the modulation through carrier frequency. There are some other parameters in there. And for phase acquisition, you undo the effects of the distortion of channel, and now you're presented with a sequence of numbers. So I think people would say that those are the received signal samples.

And if you looked at those on a plot where you have the 16 possible points, you'd have a bunch of fuzz.

A. I read it.
Q. Okay. So do you agree or disagree with that?
A. I disagree.
Q. Okay. So why do you disagree?
A. It's the same issue, that the -- so let me read the word.
What Apple, the construction says, a modulator that is a map pattern. So that's taking a group of bits and a pattern of bits and modulating it, using the terminology of the patent.
So as I've said many times, in 16 QAM you take 4 bits, and you produce one of those 16 constellation points.
So -- so the demodulator is acting in an ordinary fashion to convert or -- this is -- you have a -- at the --
The way demodulator is used here is a demapper. You already decided, for whatever receiver mechanism you had, that the input of the demodulator is one of 16 points. So the demodulator is simply a demapper into -- one of those 16 points into 4 bits. And that's -- you know.
And -- and Apple is not claiming that a symbol is itself a pattern. It's a modulated pattern. So it's taking the pattern and then modulating it to one of

16 points. That's what a symbol is.

Q. Let's -- let's turn to the next section of Dr. Wessel's declaration.

A. Where are you?

Q. On subsection B, between paragraphs 25 and 26.

THE WITNESS: I'm going to need to take a break in a couple of minutes. Is this a good place to take it now? I want to go to the bathroom.

MR. BRIGGS: Yeah.

THE VIDEOGRAPHER: We're going off the video record. It's 2:17 p.m.

(Recess from 2:17 p.m. until 2:28 p.m.)

THE VIDEOGRAPHER: We're on the video record. Its 2:28 p.m.

BY MR. BRIGGS:

Q. Dr. Gitlin, can you turn back to page 5 of Dr. Wessel's declaration.

So I wanted to ask you some more questions about Samsung's alternative construction. We just talked about the first part that says a "modulated signal," and you disagreed that that was correct.

Now I want to ask you if you disagree with the remainder of that proposed construction, which states --

A. How would you parse it?

Q. Well, that part says that a symbol represents a number of bits specified according to the modulation technique.

I mean, would you agree that a symbol represents a number of bits specified according to a modulation technique?

A. Yes.

Q. Okay. So your real issue with Samsung's proposed construction is the portion that states "a modulated signal"?

A. Yes.

Q. And you don't agree that it's a signal; you believe it's a modulated pattern?

A. Yes. And that -- that language is what -- the way the patent refers the use of the word "modulator." I mean, as I said many times, I'm -- every time I'm seeing that "modulator," I'm saying "mapper," because that's the language that I'm familiar with, a bit mapper. You map bits into the signal -- to a symbol, excuse me.

Q. Yeah, we've got a lot of tongue twisters today.

MR. KOLOVOS: And given that the whole dispute seems to be is it "symbol" or is it "signal."

MR. BRIGGS: Hopefully you've been watching over us.

MR. KOLOVOS: I've been trying to, trying to, trying keep an eye on that.

Q. Can you turn to page -- or paragraph 38 of Dr. Wessel's declaration?

A. Let me -- let me just -- this is in...

Q. And you might want to refer back to paragraph 74 of your declaration.

A. There's where I'm going.

I have paragraph 74. Let's make sure I got to the end of it. Yeah. Okay. 38. Let me -- it goes on to the next page.

Okay. I think I read them all.

Q. Okay. So why don't we start with paragraph 74 of your declaration.

You make a statement in the middle of this paragraph that it would be -- you state, "It would be incorrect to refer to the entire sequence as a single symbol. Accordingly, a construction for symbols such as a signal representative data would be incorrect because it would fail to distinguish between a single symbol and a sequence of such symbols."

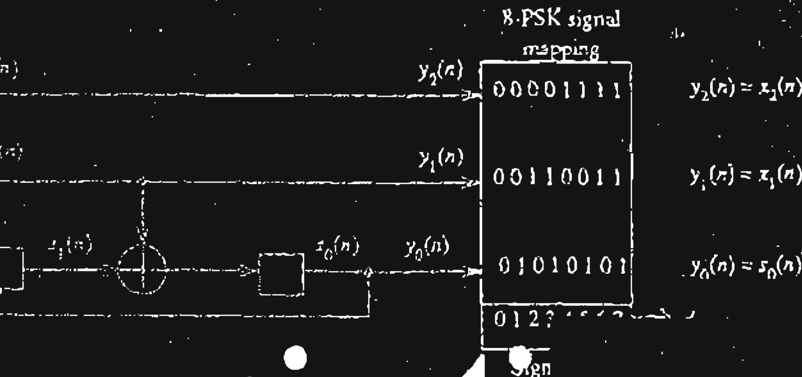
Okay. So what is -- what is your concern that you're expressing here in paragraph 74?

MR. KOLOVOS: Objection.

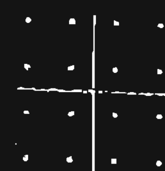
A. It's, as I recall, it's intended to distinguish between a symbol and a signal. I mean, it's that the --

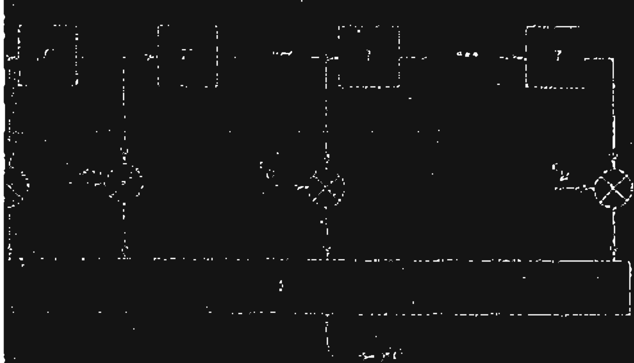
Exhibit E

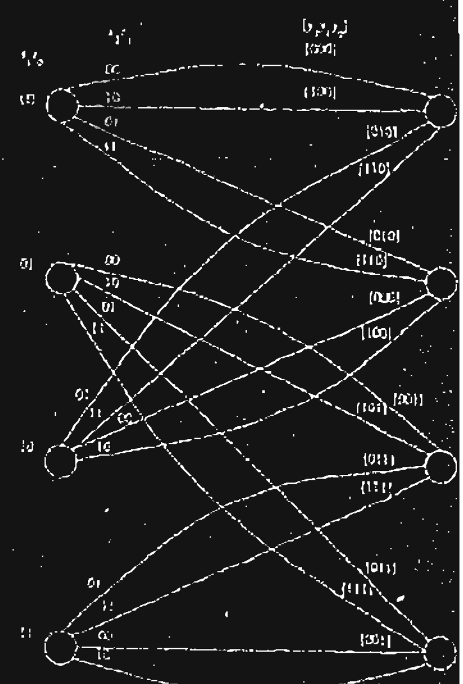
Applications of Communications Theory
Series Editor: R. W. Lucky



Data Communications Principles







Richard D. Gitlin
Jeremiah F. Hayes
Stephen B. Weinstein

one is presented with statistical data whose probability distribution depends on a discrete set of underlying parameters. Decision theory offers tools for processing the data to enable one to choose among these parameters in a statistically optimal fashion. Specifically, we shall be applying elements of the theory to the detection of signals in a digital communication system in which one of a finite set of symbols is transmitted over a channel.

The derivation of optimum decision rules begins with the definition of what is called the *observation space*. This is the raw data that are to be processed by the receiver. The dimensions of this space depend upon the particular application at hand, and the points in the space are the observed output of the channel. Consider the following simple one-dimensional example. A zero or a one is conveyed over a pair of wires by voltage levels of $+s$ or $-s$, respectively. A single observation of the voltage is made. We assume that this observation is disturbed by additive noise, giving

$$Y = X + N, \tag{2.1}$$

where $X = +s$ or $-s$. Assume that the noise voltage, N, is a zero mean Gaussian random variable.* The observation space in this case is the range of values assumed by the random variable Y.

Because of the random nature of the channel, different transmitted symbols may be mapped into the same point in the observation space. In general, all that distinguishes these different transmitted symbols at the channel output are different conditional probability distributions. In the example of (2.1), conditioned on the transmitted symbol, Y is a Gaussian random variable with either mean $+s$ or mean $-s$. The essential task of detection theory is to decide among the conditional distributions based on the observed values of Y. In the above example this is done by partitioning the observation space into two nonoverlapping regions (Figure 2.2) which cover the whole space. More generally, when one of L symbols is transmitted, the observation space is partitioned into L regions. Each region is identified with a transmitted symbol; a channel output falling in a particular region leads to deciding that the corresponding symbol was transmitted.

The choice of the criterion for partitioning the space led to a great deal of controversy in the formative years of detection theory. Part of the difficulty was in the assignment of *a priori* probabilities to the parameters of the distributions. Fortunately, matters are considerably simplified in the communications context, since the *a priori* probabilities of the transmitted symbols are known. In communications systems, there is also a convenient criterion for partitioning the

* The Gaussian random variable, which is defined in Appendix 2A, along with other probabilistic concepts, is often a remarkably robust assumption. Many physical processes can be modeled as Gaussian. In other cases where the noise is, strictly speaking, not Gaussian, it can sometimes be assumed Gaussian for the purposes of comparing alternative systems and techniques, considerably simplifying the mathematical analysis. Furthermore, the results obtained for a Gaussian channel often provide a lower bound on the performance of systems operating on a non-Gaussian channel.

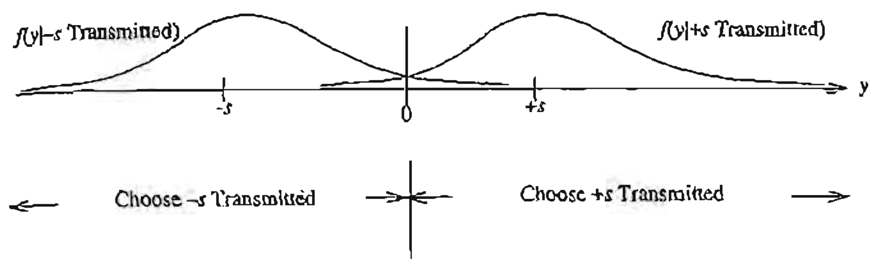


Fig. 2.2 Decision regions for one-dimensional binary transmission example.

observation space. One attempts to minimize the probability of making an error in deciding upon the transmitted symbol.

The derivation of the optimal decision regions is simplified if we assume the binary case, i.e., two transmitted symbols. The results of this analysis form the basis of the general case. The derivation of the detection rule involved partitioning the observation space into two disjoint regions; $\mathbf{R}_0$ and $\mathbf{R}_1$, each region being identified with one or the other signal. A decision is made as to whether the output of the channel falls in $\mathbf{R}_0$ or $\mathbf{R}_1$, respectively. The problem is to find the partition which minimizes probability of error. We shall assume that the observation space is of dimension M, i.e., all of the variables of equation (2.1) are vectors rather than scalars. We shall see later how signal and noise wave forms can be represented by such vectors. We generalize from $\pm s$ of the example above by supposing that the symbols s_0 and s_1 are transmitted with probabilities P_0 and P_1, respectively. If the received sample falls in region $\mathbf{R}_i$, the decision is made that s_i $(i=0,1)$ was transmitted. A detection error is made if s_0 is transmitted and the observed random variable Y falls in the region $\mathbf{R}_1$ or vice versa. The probability error given that s_0 is transmitted is denoted by

$$Pr[Error|s_0\ Transmitted] = Pr[\mathbf{Y} \in \mathbf{R}_1|s_0\ Transmitted]$$

and, similarly,

$$Pr[Error|s_1\ Transmitted] = Pr[\mathbf{Y} \in \mathbf{R}_0|s_1\ Transmitted].$$

From the law of total probability, we may write the probability of error as

$$\begin{aligned} Pr[Error] &= Pr[Error,\ s_0\ Transmitted] + Pr[Error,\ s_1\ Transmitted] \\ &= P_0\ Pr[\mathbf{Y} \in \mathbf{R}_1|s_0\ Transmitted] + P_1\ Pr[\mathbf{Y} \in \mathbf{R}_0|s_1\ Transmitted]. \end{aligned} \tag{2.2}$$

We now derive the rule for choosing $\mathbf{R}_0$ and $\mathbf{R}_1$ which minimizes the probability of error. In case of a continuous channel output, we have

$$Pr[Error] = P_0 \int_{\mathbf{R}_1} f(\mathbf{y}|\mathbf{s}_0 \; Transmitted) \; d\mathbf{y} + P_1 \int_{\mathbf{R}_0} f(\mathbf{y}|\mathbf{s}_1 \; Transmitted) \; d\mathbf{y} \; , \tag{2.3}$$

where $f(\mathbf{y}|\mathbf{s}_i \; Transmitted)$, $i = 0,1$ is the probability density function of the channel output conditioned on the transmitted signal. Integration is over the multidimensional regions $\mathbf{R}_1$ and $\mathbf{R}_0$, respectively.

In the case of a discrete channel output, the probability of error may be written as:

$$Pr[Error] = P_0 \sum_{\mathbf{y}_j \in \mathbf{R}_1} Pr(\mathbf{Y}=\mathbf{y}_j|\mathbf{s}_0 \; Transmitted)$$

$$+ P_1 \sum_{\mathbf{y}_j \in \mathbf{R}_0} Pr(\mathbf{Y}=\mathbf{y}_j|\mathbf{s}_1 \; Transmitted) \; , \tag{2.4}$$

where $\mathbf{y}_j$, $j = 1,2...,M$, are the points in the observation space and $Pr(\mathbf{Y}=\mathbf{y}_j|\mathbf{s}_i \; Transmitted)$, $i = 0,1$, are the appropriate conditional probabilities.

Since $\mathbf{R}_0$ and $\mathbf{R}_1$ partition the observation space, $\mathbf{R}_0 \cap \mathbf{R}_1 = \phi$ and $\mathbf{R}_0 \cup \mathbf{R}_1 = \Omega$, where ϕ denotes the null space and Ω denotes the whole space. Based on these relations, and the fact that

$$\int_{\mathbf{R}_0} f(\mathbf{y}|\mathbf{s}_0 \; Transmitted) \; d\mathbf{y} + \int_{\mathbf{R}_1} f(\mathbf{y}|\mathbf{s}_0 \; Transmitted) \; d\mathbf{y}$$

$$= \int_{\Omega} f(\mathbf{y}|\mathbf{s}_0 \; Transmitted) \; d\mathbf{y} = 1 \; ,$$

we may express (2.3) in the following form which makes the minimization problem straightforward:

$$Pr[Error] = P_0 \int_{\Omega} f(\mathbf{y}|\mathbf{s}_0 \; Transmitted) \; d\mathbf{y} + \int_{\mathbf{R}_0} \{ -P_0 \, f(\mathbf{y}|\mathbf{s}_0 \; Transmitted)$$

$$+ P_1 \, f(\mathbf{y}|\mathbf{s}_1 \; Transmitted) \} \; d\mathbf{y}$$

$$= P_0 + \int_{\mathbf{R}_0} \{ P_1 f(\mathbf{y}|\mathbf{s}_1 \; Transmitted) - P_0 \, f(\mathbf{y}|\mathbf{s}_0 \; Transmitted) \} \; d\mathbf{y}. \tag{2.5}$$

The only unknown quantity in (2.5) is the set of points which compose $\mathbf{R}_0$. Observe that $Pr[Error]$ can be minimized by placing in $\mathbf{R}_0$ only those points for which the integrand is negative. The proof that this leads to a minimum is by contradiction. Suppose that $\mathbf{R}_0$ contains a set of points for which the integrand is positive. The probability of error can be decreased simply by placing these points in $\mathbf{R}_1$. Points which are exactly equal to zero can be placed in either region without changing the probability of error.

Since they are the product of positive quantities, a probability and a probability density, the two terms in the integrand of (2.5) are positive and the integrand is negative at a point y if

$$\frac{P_0 f(\mathbf{y}|s_0\ Transmitted)}{P_1 f(\mathbf{y}|s_1\ Transmitted)} = \frac{Pr(s_0\ Transmitted|\mathbf{Y}=\mathbf{y})}{Pr(s_1\ Transmitted|\mathbf{Y}=\mathbf{y})} > 1 . \quad (2.6a)$$

Thus the decision rule that minimizes the probability of error is "decide s_0 was transmitted if (2.6a) is true and s_1 otherwise."

The decision rule in (2.6a) chooses the signal which maximizes the *a posteriori probability* of the transmitted symbol, given the observation; accordingly, it is called the maximum *a posteriori* (MAP) detector. As we shall see when we treat source coding in Section 2.4.2, for efficient transmission the *a priori* probabilities should be equal, $P_0 = P_1$. In this case the rule is to declare that s_0 was transmitted if

$$f(\mathbf{y}|s_0\ Transmitted) > f(\mathbf{y}|s_1\ Transmitted) , \quad (2.6b)$$

otherwise, choose s_1 as the transmitted symbol.

EXAMPLE 1 We now apply the MAP detector to the one-dimensional Gaussian example that we considered in (2.1) above. Since the Gaussian noise has zero mean and mean square value σ^2, the probability density of Y is

$$f(y|s_i\ Transmitted) = \exp(-(y\pm s)^2/2\sigma^2)/\sqrt{2\pi\sigma^2} .$$

Applying (2.6), we have the decision rule "choose the transmitted signal as s if

$$\exp(-(y-s)^2/2\sigma^2) > \exp(-(y+s)^2/2\sigma^2) ."$$

Taking logarithms of both sides, we have, after some manipulation, the threshold rule, which is to choose $+s$ as the transmitted signal if

$$y > 0.$$

The decision space is shown in Figure 2.2, along with the conditional probability density functions. A similar development can be followed in the case of a discrete observation space. Again, the probability of error is minimized by choosing the maximum *a posteriori* estimate (MAP)

$$\frac{P_0 Pr(\mathbf{Y}=\mathbf{y}_j|s_0\ Transmitted)}{P_1 Pr(\mathbf{Y}=\mathbf{y}_j|s_1\ Transmitted)} = \frac{Pr(s_0\ Transmitted|\mathbf{Y}=\mathbf{y}_j)}{Pr(s_1\ Transmitted|\mathbf{Y}=\mathbf{y}_j)} \quad (2.7a)$$

In the case of equal *a priori* probabilities, it can be shown that the probability of error is minimized for each $\mathbf{y}_j$, $i = 1,2,\ldots,M$, in the observation space by choosing s_0 as the transmitted signal if

$$Pr(\mathbf{Y} = \mathbf{y}_j|s_0\ Transmitted) > Pr(\mathbf{Y} = \mathbf{y}_j|s_1\ Transmitted) . \quad (2.7b)$$

Otherwise, choose s_1 as the transmitted signal.

EXAMPLE 2 Consider the following example for the discrete case. Suppose that two signals are transmitted with equal probability over an optical fiber line. At the receiver, we assume that the optical detector emits electrons at a Poisson rate whose mean value depends upon the transmitted signal. For the two possible transmitted signals, s_0 and s_1, we denote these averages as λ_0 and λ_1 electrons per second, respectively. We decide which of the two signals was transmitted by counting the number of electrons emitted in a t second interval. Let Y_t denote the number of electrons emitted by the optical detector over the observation interval $(0,t)$; then the receiver decides in favor of s_0 over s_1 if the actual number of observed electrons, n, is such that

$$Pr(Y_t = n|s_0 \; Transmitted) \; > \; Pr(Y_t = n|s_1 \; Transmitted).$$

Since the number of emitted electrons is a Poisson* random variable, we have

$$Pr[Y_t = n|s_i \; Transmitted] = \exp(-\lambda_i t) \; (\lambda_i t)^n/n!, \; i = 0,1, \; n = 0,1,2,...$$

Since Y_t conditioned on the transmitted signal is a Poisson random variable, we choose s_0 over s_1 as the average rate if

$$\exp(-\lambda_0 t) \; (\lambda_0 t)^n/n! \; > \; \exp(-\lambda_1 t) \; (\lambda_1 t)^n/n!$$

or

$$n \; > \; (\lambda_0 - \lambda_1)t/(\ln \lambda_0 - \ln \lambda_1).$$

The equation says to choose the decision rule that says to select s_0 if the number of electrons is greater than the threshold on the right-hand side.

There is a related approach to decision making which results in the same decision rule as (2.6b) when the *a priori* probabilities are identical. The technique is called *maximum likelihood*. Given the received signal y one chooses the input which maximizes the likelihood $f(y|s_i \; Transmitted)$, $i = 0$ or 1. Maximum likelihood is appropriate when there is no way of determining the *a priori* probabilities P_0 and P_1. For example, in radar, where one attempts to detect the presence or absence of a reflected signal, the *a priori* probabilities generally have no meaning. In this case decisions are made on the basis of costs associated with each kind of error.

2.1.2 *L*-ARY TRANSMISSION

In many applications the channel can be utilized more efficiently by using L-ary transmission, where one of $L > 2$ symbols, s_i, $i = 0,1...,L-1$ is transmitted. It is almost always true that L is a power of two, $L = 2^l$, so that

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* See Appendix 2A for the definition of a Poisson random variable.

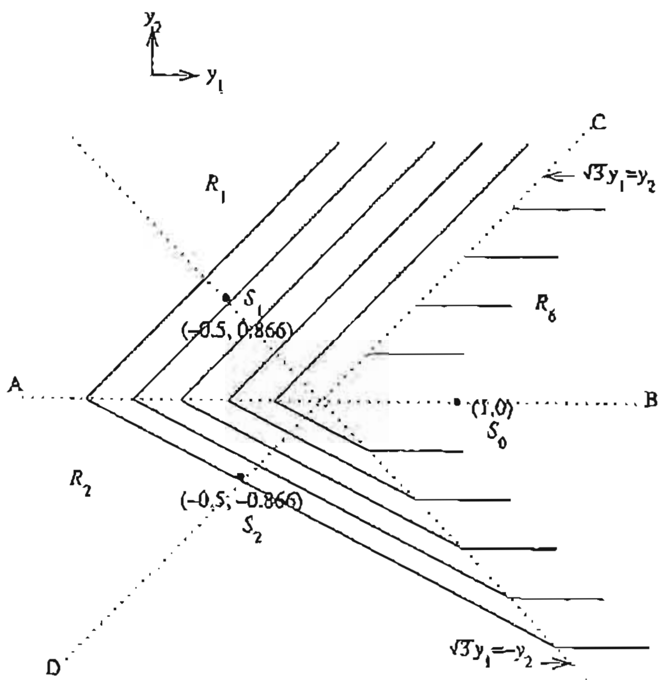

Fig. 2.3 Optimum decision boundaries: $L = 3$.

encoding a binary data stream is straightforward; each symbol conveys $\log_2 L$ bits.*

The results that we have obtained for the detection of binary signals apply directly to L-ary transmission. We imagine that the search for the most probable transmitted signal is conducted by comparisons of all possible pairs of transmitted signals. In the continuous case, the transmitted signal is chosen as s_i, where i is the value of the index such that $P_i\ f(\mathbf{y}|s_i\ Transmitted)$ is maximum over $i = 0,1,...,L-1$ and where P_i is the probability that s_i is transmitted. In the discrete case, for a channel output i, s_l is chosen such that $P_l\ Pr(Y = y_j|s_i\ Transmitted)$ is maximum over $i = 0,1,...,L-1$. In the usual communications context, where all transmitted symbols are equally probable, the above decision rule is equivalent to maximum likelihood.

The partitioning of the two-dimensional observation space for the simple case of $L = 3$ is shown in Figure 2.3. Let the transmitted symbols be represented by points on the plane, $s_0 = (1,0)$, $s_1 = (-0.5,\ 0.866)$, and $s_2 = (-0.5,\ -0.866)$. (In Chapter 5, we shall see that these points might represent the phases of a sinusoidal carrier.) Let us assume that each of the two

* In speaking of transmitting in bits per second, we are using the expression in its commonly used sense; however, as we shall see in Section 2.4, there is a mathematically rigorous definition of the information-bearing content of a signal in bits.

components of the signal point representing a symbol is disturbed independently by additive Gaussian noise with mean square value σ^2. We also assume that the signals are equally probable. Since the noise components are independent, the joint conditional densities are the product of the marginals. The conditional densities of the channel outputs are:

$$f(\mathbf{y}|s_0\ Transmitted) = \exp(-((y_1 - 1)^2 + y_2)/2\sigma^2)/2\pi\sigma^2$$

$$f(\mathbf{y}|s_1\ Transmitted) = \exp(-((y_1 + 0.5)^2/2 + (y_2 - 0.866)^2/2\sigma^2)/2\pi\sigma^2$$

$$f(\mathbf{y}|s_2\ Transmitted) = \exp(-((y_1 + 0.5)^2/2 + (y_2 + 0.866)^2/2\sigma^2)/2\pi\sigma^2$$

The derivation now proceeds in the same fashion as that of the one-dimensional Gaussian example considered above. The signal s_0 is chosen over s_1 if

$$\|\mathbf{Y} - s_0\|^2 < \|\mathbf{Y} - s_1\|^2,$$

where $\|\cdot\|$ denotes the familiar Euclidean distance. It is interesting to note that the latter relationship describes a detector that chooses the transmitted signal that is *closest* to the received signal vector. The concept of a receiver which decides in favor of the signal that is at the *minimum distance* from the received signal is an important attribute of many of the receivers we will discuss later in this book. Returning to the above example, we find that after some manipulation, this leads to the criterion choose s_0 over s_1 transmitted if $\sqrt{3}\ y_1 \geq y_2$. The remaining regions are found the same way, with the result in the form of optimum decision regions shown in Figure 2.3. As we see from the figure, the boundaries of the decision regions are the perpendicular bisectors of the lines connecting the signal points.

2.1.3 PERFORMANCE—THE UNION BOUND

It is essential to describe the performance of these optimum detectors. In principle, the calculation of performance, i.e., the probability of making an error, is quite direct for the binary case. Having derived the optimum decision regions R_0 and R_1, one may evaluate (2.3) and (2.4) for the continuous and discrete cases, respectively. In this chapter we shall consider calculations of performance for two types of channels, the additive white Gaussian noise (AWGN) channel and the binary symmetric channel (BSC).

The calculation of performance is somewhat more complicated in the case of L-ary transmission, $L > 2$. From the law of total probability, we may write

$$Pr[Error] = 1 - Pr[Correct] = 1 - \sum_{i=0}^{L-1} P_i\, Pr[Correct|s_i\ Transmitted]$$

$$= 1 - \sum_{i=0}^{L-1} P_i\, Pr[\mathbf{Y} \in \mathrm{R}_i|s_i\ Transmitted]. \tag{2.8}$$

The key to evaluating the probability of error is the calculation of the term

$$Pr[Y \in R_i | s_i \ Transmitted] = \int_{R_i} f(y | s_i \ Transmitted) \ dy \qquad (2.9a)$$

in the continuous case, and

$$Pr[Y \in R_i | s_i \ Transmitted] = \sum_{y_i \in R_i} Pr(Y = y_i | s_i \ Transmitted) \qquad (2.9b)$$

in the discrete case.

There are many situations in which the calculation of the quantities in (2.9a–b) is not straightforward. We shall see several examples later in the text. In these situations, we can obtain a useful upper bound on the error probability by applying the *union bound*, which is composed of errors involving only pairs of signals.

Suppose that the transmitted signal is s_i. Let E_{ij} denote the event that the observed point is such that s_j rather than s_i would be chosen. For example, in Figure 2.3, the event E_{12} would occur if the observation falls below the line A–B when s_1 is transmitted. The actual error event consists of the union of these events over all $j \neq i$, and we may write

$$Pr[Error | s_i \ Transmitted] = Pr[\bigcup_{i \neq j} E_{ij}]. \qquad (2.9c)$$

It is important to observe that the events E_{ij} and E_{ik}; $i \neq j \neq k$ are not disjoint. This is obvious in the example in Figure 2.3 where E_{12} and E_{10} have considerable overlap since E_{10} consists of points to the right of C–D. An application of the standard laws of probability to (2.9c) yields the *union bound*

$$Pr[Error | s_i \ Transmitted] \leq \sum_{i \neq j} Pr[E_{ij}]. \qquad (2.10)$$

The calculation of the pairwise errors in (2.10) is the same as we have considered for binary transmission. For example, for the case depicted on Figure 2.3, one would integrate the density conditioned on s_1 over the half plane below A–B and the half plane to the right of C–D if the transmitted signal were s_1 [see (2.3) and (2.4)].

2.2 THE ADDITIVE WHITE GAUSSIAN NOISE (AWGN) CHANNEL

2.2.1 THE MATCHED-FILTER RECEIVER

In physical channels the information symbols are translated into time-varying waveforms or pulses whose form is suitable for transmission over the

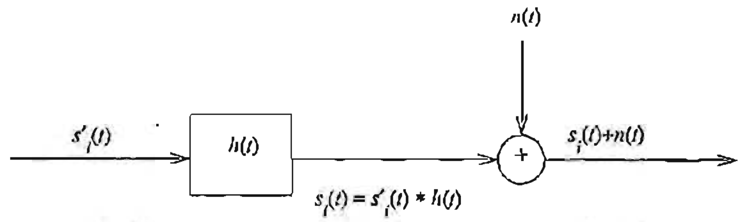

Fig. 2.4 The additive, linear noisy, communications channel.

channel. In a general sense, this process is called *modulation*.* We begin with the binary case, where the waveforms $s'_0(t)$ and $s'_1(t)$ are transmitted for a zero and a one, respectively. There are many practical examples of modulation techniques. Perhaps the most basic, known as non-return to zero (NRZ), is the encoding of a zero into a positive pulse and a one into its negative. In frequency shift keying† (FSK), data bits are represented by bursts of carrier at different frequencies. Over a short time interval we have $s'_i(t) = \sin(2\pi f_i t)$, $i = 0,1;\ f_0 \neq f_1$.

The signal is transmitted over the channel, where it is subject to the impairments discussed in Section 1.6 of Chapter 1. The model of the channel is depicted in Figure 2.4. The transmitted signal suffers delay and attenuation distortion represented by the channel which has impulse response $h(t)$ and the corresponding transfer function $H(f)$. In this chapter, we shall assume that $h(t)$ or, equivalently, $H(f)$ is known at the receiver. Random impairments are presented by additive noise. We also assume that there is no intersymbol interference, where energy from one symbol spills over into adjacent symbol intervals. Under this assumption, we can consider the detection of a single signal in isolation.**

Under these assumptions, the output of the channel may be written

$$y(t) = s_i(t) + n(t),\ i = 0,1\ , \tag{2.11}$$

where $s_i(t)$ is the convolution of the transmitted signal with the channel impulse response, $s_i(t) = s'_i(t) * h(t)$, $i = 0,1$.‡ The detection problem is to decide upon the transmitted signal, $s'_0(t)$ or $s'_1(t)$, based upon the output of the channel as represented in (2.11). Since the impulse response of the channel is known at

* There are often two levels of modulation in digital communication systems: the first level maps customer information, e.g., a binary stream, into a discrete set of signals, and the second level translates the signals into a form which is suited to the transmission media,.modulation into a passband channel.

† See Section 5.6 for a discussion of FSK.

** In Chapter 4 intersymbol interference and the effect of channel shaping and of transmitter and receiver filtering are considered.

‡ The symbol $*$ indicates convolution $s'_i(t) * h(t) = \int_{-\infty}^{\infty} s'_i(\tau) h(t-\tau)\,d\tau = \int_{-\infty}^{\infty} s'_i(t-\tau) h(\tau)\,d\tau$.