programming to the satellite, it will send the same programming via wide-band digital links to a network of ground repeaters in urban areas. These terrestrial repeaters will simulcast the satellite signal, i.e. transmit the same channels of CD-quality programming as does the satellite using the same unique Dolby modulation technique, thus compensating as needed for any shadowing in "urban canyons". User radios will automatically select the stronger of the satellite signal or the terrestrial signal carrying the same program. For simplicity, Channel "20" on all three satellite beams of the satellite will also be Channel "20" on the terrestrial repeater, even though the actual frequencies for those transmissions will be different.3/

CD Radio, Inc. proposes to render service on a private carrier basis by selling transponders to both terrestrial broadcasters and to non-broadcasters providing subscription or pay-per-listen services.

III. BASIC APPLICANT INFORMATION

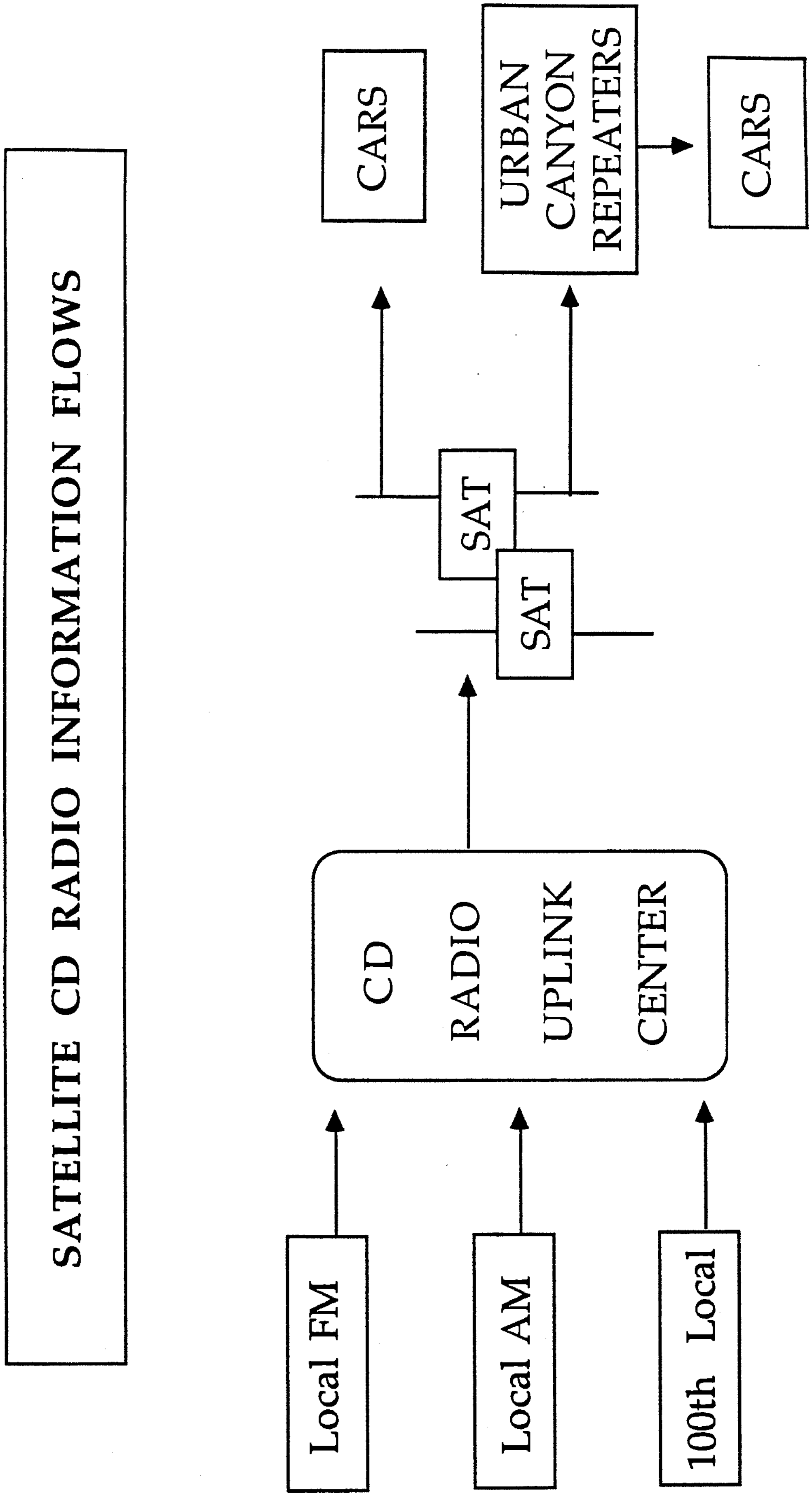
A. Name and Address of Applicant

Satellite CD Radio, Inc.
Techworld Plaza
800 K Street, N.W.
Suite 750
Washington, D.C. 20001

B. Correspondence should be directed to:

3/ The information flow for the satellite CD radio system is schematically described in Figure 1.

Figure 1



SATELLITE CD RADIO INFORMATION FLOWS
Local FM
Local AM
100th Local
CD RADIO UPLINK CENTER
SAT
SAT
CARS
URBAN CANYON REPEATERS
CARS

Peter Dolan
President
Satellite CD Radio, Inc.
Techworld Plaza
800 K Street, N.W.
Suite 750
Washington, D.C. 20001

IV. <u>TECHNICAL QUALIFICATIONS</u>

CD Radio, Inc., is technically qualified to provide the requested service, as evidenced by the technical showing contained in each of the two applications attached to this system proposal, incorporated herein by reference. A highly qualified team of satellite engineers and industry analysts from Stanford Telecommunications, Telecommunication Systems, and MARCOR, Inc., has been assembled to produce a system design which is optimal from both a technical and business standpoint. See Figure 2.

V. <u>FINANCIAL QUALIFICATIONS</u>

The Board of CD Radio, Inc., represents a cross section of successful business interests in the satellite and radio fields. The principals of CD Radio have a track record of successfully financing the projects they undertake.

<u>Capital Costs</u>

Capital outlays for the CD Radio System are $275 million based on a carefully designed project financing structure. Cash

Satellite CD Radio, Inc.
Petition For Rulemaking
May 18, 1990

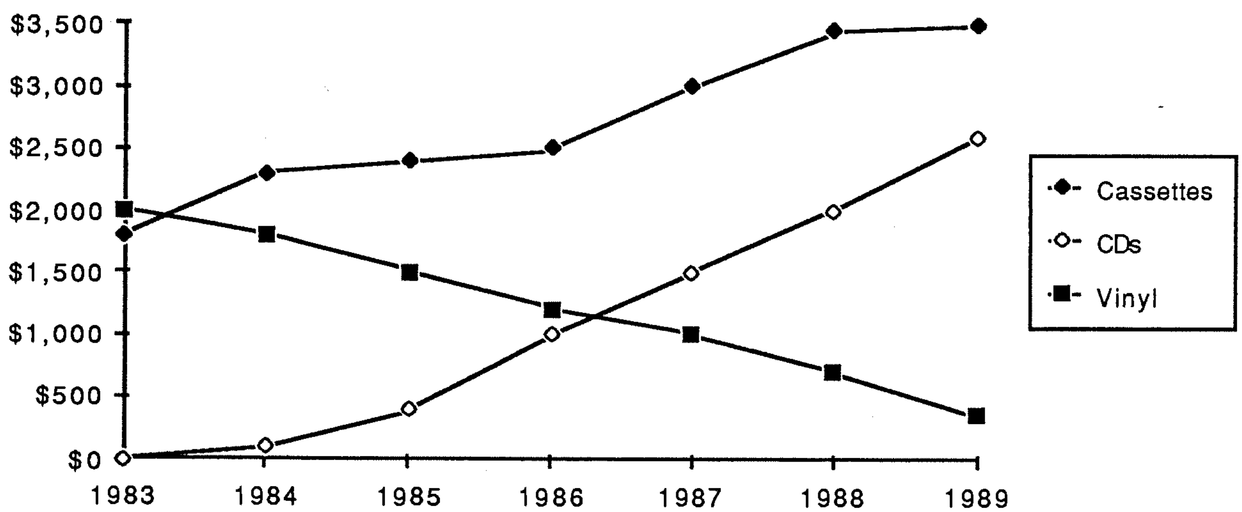
Appendix 1

Analysis of the Market for CD Radio

THE INDUSTRY

With the advent of compact discs, the listening public has become acutely aware of the audio benefits of digital sound. Since compact discs were introduced, its sales have practically eclipsed the existence of vinyl records. The following chart graphically demonstrates the impact of CD's on the recording industry:

RECORDING INDUSTRY SALES
Annual Sales (in millions)

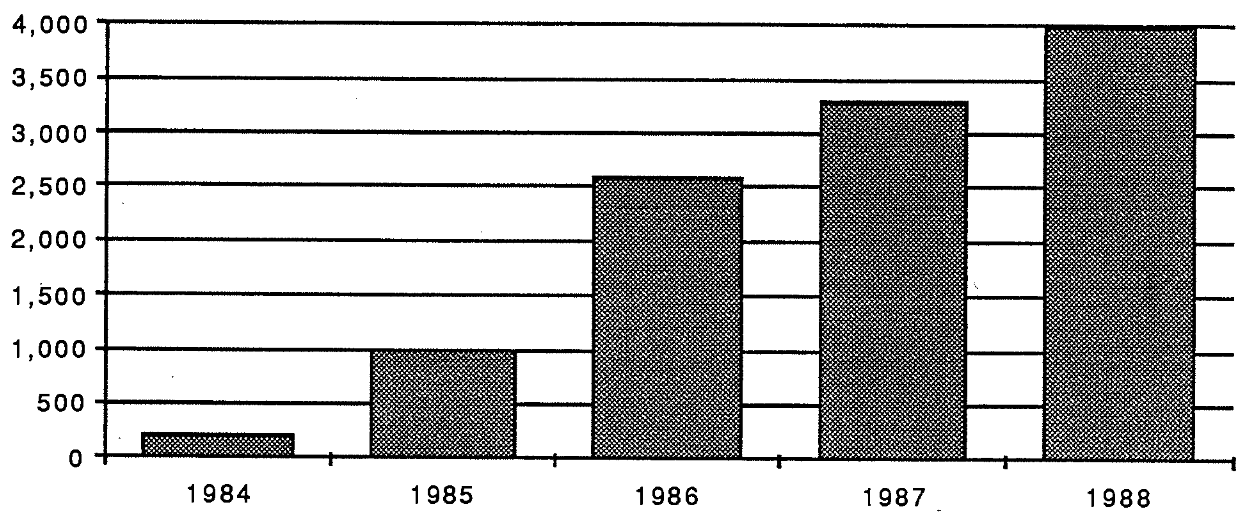


Source: Recording Industry Association

Cassette tape sales have leveled off in recent years and vinyl record sales have declined dramatically over the six year period. Only CD sales have sustained continued growth. Consumers have demonstrated their preference for high quality sound by paying as much as $15 for a compact disc when the same material is available on vinyl album or cassette tape for as little as $7. As CD prices continue to fall, an increasing number of buyers are opting for its superior listening quality.

The increase in CD sales is the direct result of the tremendous acceptance of CD players in consumer homes. Compact Disc players now inhabit 19% of U.S. homes with penetration increasing on declining unit prices. The following chart displays the historical growth of compact disc players:

COMPACT DISC PLAYER SALES (ESTIMATED)
(in thousands)



Source: Consumer Electronics Report

One of the reasons cassette tapes have remained a popular medium is because it has the capability of being played and recorded on. Once the copyright problems surrounding the introduction of Digital Audio Tape (DAT) recorders have been solved, it is widely anticipated that cassette tapes will suffer the same destiny of vinyl records and be replaced by a digital device.

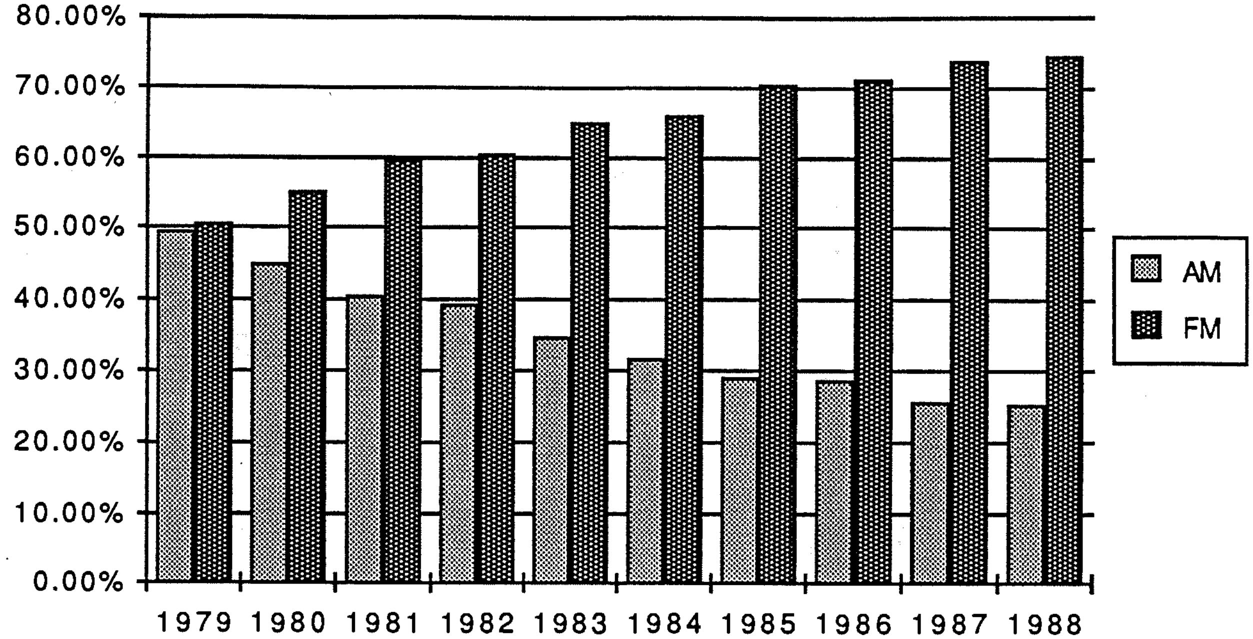
Listening audiences are demanding the same type of high quality sound from the radio broadcasting industry. However, due to the inherent limitations of existing radio transmitting means, broadcasters are ill-equipped to respond to the demand of their audiences. AM and FM bands are plagued with congestion and interference. Normal FM radio transmission is an analog process which is limited to 15 KHz audio bandwidth and subject to noise and distortion caused by atmospherics, signal processing and multipath reception effects. Good stereo reception is practically impossible in cars where reception suffers dramatically from multipath propagation.

The demand for and unavailability of CD quality radio has been recognized by the cable industry. Three companies are now offering digital radio systems which will provide cable customers with high quality, commercial-free music delivered to their home stereo systems. The service will cost between $8 and $10 per month. The companies involved are:

Company	**Service**
International Cablecasting	*CD/8*
General Instrument	*Digital Cable Radio*
Digital Radio Lab	*Digital Radio Channel*

According to a National Association of Broadcasters document, the companies expect to reach a 10% penetration of the 52 million cable households within the next 2 to 3 years. Research conducted by A.C. Nielsen suggests that about 14% of cable households surveyed are "very likely" to subscribe to the Digital Radio Channel service at $7.50 per month. Digital Radio Labs is affiliated with HBO and Viacom which indicative of broad support for the service. In addition to the monthly service fee, the DRC system costs about $2,000 to add a cable headend which the customer will have to purchase or lease.

The radio industry itself has established a precedent for the acceptance of advanced sound quality. With the introduction of FM radio, AM broadcasters have progressively attracted smaller audiences. The FM radio band is located in a higher frequency band than its AM counterpart and is therefore less susceptible to static, fading and background overlapping than AM transmissions. The following chart demonstrates the relative AM and FM audience shares over the past 16 years:



Source: R&R Magazine

It is therefore clear that listening audiences understand and respond to the quality of digital sound. When it first became available in the form of compact discs, they were prepared to purchase another component for their home stereo systems and pay roughly twice the price of vinyl records for the compact discs themselves. Focusing on radio, consumers are paying a service fee to cable operators for digital sound as an alternative to the free analog transmission provided by current broadcasting means. Radio broadcasters are thus finding it increasingly difficult to contest in today's competitive marketplace with yesterday's technology.

CD Radio, Inc. (CDR) can provide the bridge between the listening public's demand for greater sound quality and the radio broadcaster's inability to deliver it. A revolutionary technology has recently been developed which will allow radio listeners to receive compact disc quality sound at home and in their cars. The technology is called Digital Audio Broadcast and has been successfully demonstrated both in Europe and the United States. CDR is laying the foundation to bring DAB to commercial application.

THE MARKET

The CD Radio system essentially provides the radio broadcaster with two dramatically innovative features:

- o *the ability to broadcast radio programming with compact disc quality sound,*
- o *the ability to reach a national or international audiences with the superior signal.*

To the listener, the attraction of compact disc quality radio is obvious. It has already been demonstrated that consumers are willing to extend themselves for high quality sound and the CDR system is the next logical step in meeting their requirements. The attraction of a national radio broadcast may not be as obvious, but it is certainly one with precedent.

System Users

National television broadcasting is a time-honored enterprise in the United States. National networks have long dominated the delivery of television programs to the American public. Radio stations have been incapable of reaching national audiences because of technological limitations and consequently have had to forfeit significant revenues related to national ad campaigns.

By utilizing the CDR system, a radio broadcaster realizes economies of scale not available to the typical local station. In reaching a national audience, the system user will be able to spread programming costs over a significantly larger base which in turn will allow the broadcaster to increase its station's programming budget. The national broadcaster will be able to present such programs as concert appearances by famous rock musicians, sporting events such as the Super Bowl or World Series, and radio "name" personalities like Larry King which until now have been out of the reach of local station operators. In addition, with a national infrastructure, the broadcaster will be able bring immediate news, financial and political developments directly to its audiences. With this type of high profile programming, the radio broadcaster will be able to garner the same type national recognition as television studios through its own particular format.

The broadcaster will realize other significant operating efficiencies in addition to programming. The following schedule presents a comparison of typical operating results for radio stations operating in large and small markets, respectively:

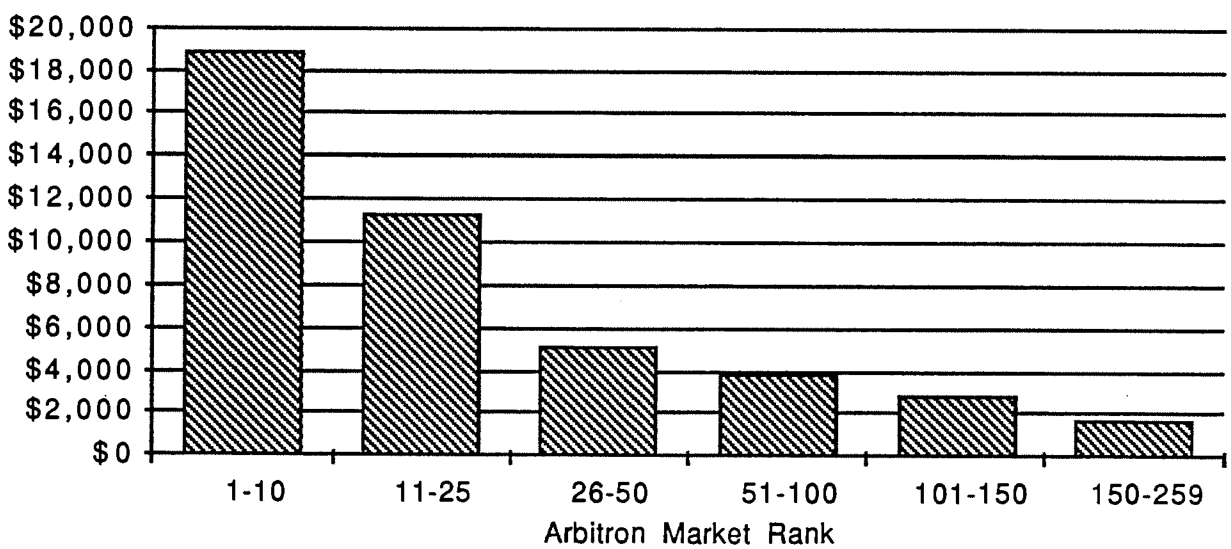
	Radio Station in Market with Population Over 2.5 Million *(in thousands)*	***Radio Station in Market with Population Between 500,000 and 1,000,000*** *(in thousands)*
Revenues:		
Network	225	23
National/Regional	2,667	485
Local	8,095	1,601
Total Time Sales	10,987	2,109
Net Revenues	9,406	1,841
Expenses:		
Technical	444	85
Programming/Production	1,747	342
News	460	65
Sales	1,373	398
Advertising/Promotion	1,076	186
General /Administrative	1,229	400
Total Operating Expenses	6,329	1,476
Operating Profit	3,077	365
Profit Margin	32.71%	19.83%

Source: Broadcast Investment Analysts, Inc.

Operating margins are highest in larger markets due to the fact that radio broadcasting is generally regarded as a fixed-cost enterprise with sales commissions normally being the only material variable cost. Because of the high ratio of fixed to variable cost, stations operating in the largest markets and generating the highest revenues will consequently experience the highest margins. This factor makes the CD Radio system a very attractive vehicle for potential broadcasters by covering national or international populations.

Acquisition prices of radio station are closely related to the size of the population they serve and the economic activity of the area. These factors determine the size of the potential listening audience and the advertising revenues that support the local station. Radio stations in larger markets are generally more profitable or have more upside potential than stations in smaller markets. Thus, prices paid for stations in larger markets are typically higher than those for comparable stations in smaller markets. The following chart illustrates average prices for stand-alone FM facility sales during the period from 1986-1987:

Average Sales Price for FM Radio Stations,1986-1987 (in thousands)



Source: Broadcast Investment Analysts, Inc.

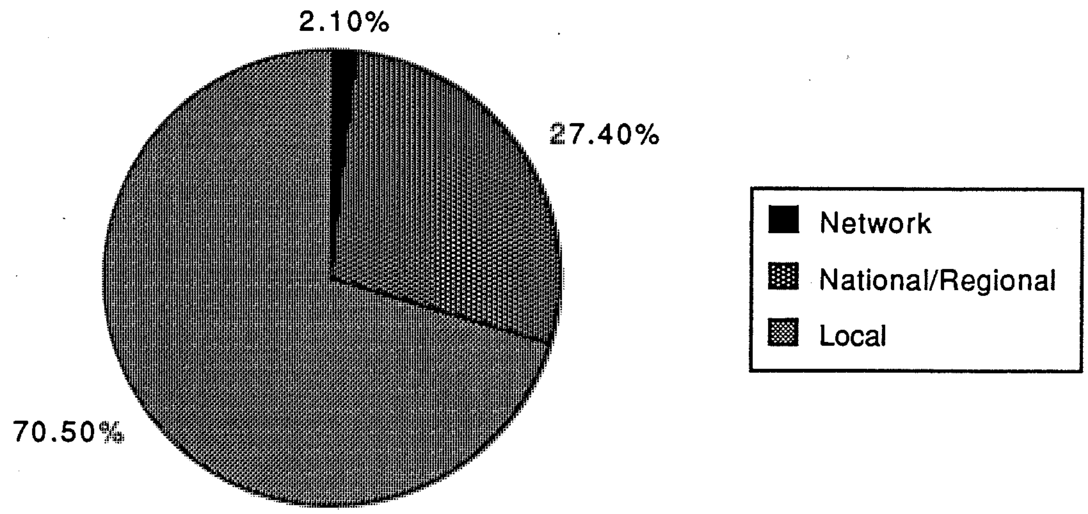
As the chart demonstrates, the value of radio stations is closely related to the size of the market in which it is located. As the CDR system has the capacity of delivering a national or international audience, only a little imagination is required to comprehend the resulting value to a well managed programming entity.

The potential users of the CDR system are numerous. First and foremost will be local stations seeking to become national "superstations". Television networks and cable companies with programming experience are also likely candidates. In essence, almost any media distribution company, including newspaper and magazine publishers could emerge as national broadcasters on a very profitable basis.

Advertisers

Commercial radio stations earn the majority of their revenues from the sale of airtime to advertisers. There are generally two classifications of advertising revenues: national and local. Historically, local advertising has comprised the majority of a stations overall revenues. The following diagram displays the various components of a typical radio station's advertising revenues operating in a large market:

Advertising Revenue Sources in Large Markets



Source: National Association of Broadcasters

Companies seeking to market products and services through mass communication mediums have concentrated on television as a means of reaching potential customers. Radio broadcasters have never gained the full attention of national advertisers primarily as a result of technological and logistical problems. Radio is unquestionably the most fragmented of all mediums in the broadcast industry. Today there are approximately 9,000 commercial radio stations operating throughout the country. Attempting to coordinate a national ad campaign among the vast number of stations has proven to be an overwhelming exercise.

In placing radio commercials on individual stations, national advertisers have normally utilized the services of large advertising agencies. The advertising firm will purchase "spot time" from the stations to air the commercials. It is the responsibility of the advertising firm to place the commercial on particular stations which will most effectively reach the client's target market. For this service, the firm will receive a commission from the radio station for selling the air time and also a fee from the advertiser for placing the ad which serves to significantly increase overall marketing costs.

Verifying performance of radio ads is cumbersome and uncertain at best. For the most part, verification is in the form of signed affidavits which creates a tremendous clerical burden in tracking paperwork. In addition, as the advertising firm is responsible for placing the ad on local stations across the country, effectiveness and therefore cost justification is difficult to determine.

A national broadcaster using the CDR system will solve a multitude of problems previously experienced by national radio advertisers:

- o by centralizing radio advertising with one national station, an advertiser will greatly reduce the logistical inefficiencies of verification,

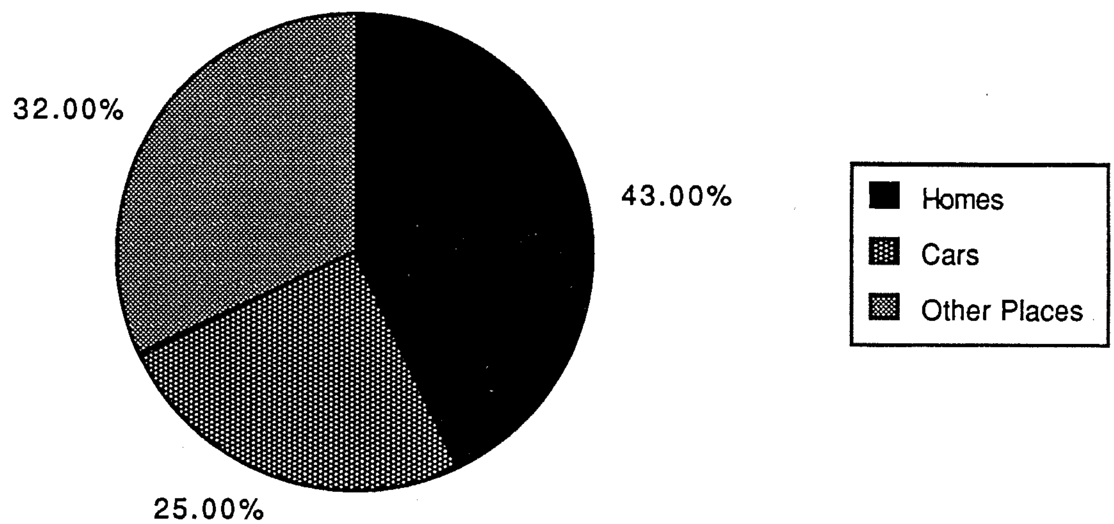
- o consumer response to radio advertising will be far easier to monitor by focusing on one station rather than numerous independent stations,

- o a national advertiser's in-house marketing staff will for the first time be able to contract with a single broadcaster for commercial time. As a result, significant efficiencies will be realized in eliminating the advertising firm's fees for placing radio ads thereby reducing overall marketing costs. Lower marketing costs will in turn attract additional advertisers serving to expand the national radio advertising revenue base.

A national radio broadcaster can provide an advertiser with an effective alternative to television. The comparable cost of television advertising greatly exceeds that of radio. With the technological and logistical drawbacks of national radio advertising being solved, companies are sure to rethink their commercial delivery strategies.

Radio advertising will offer marketing benefits which television cannot duplicated. Radio broadcasting delivers audiences largely unreachable by television such as individuals in cars and outside their homes. According to the National Association of Broadcasters, current FM audiences can be segregated as follows:

FM Audiences



As the diagram indicates, approximately 57% of FM audiences listen to radio away from home where the overwhelming majority of television viewing takes place. A broadcaster on the CDR system will provide the national advertiser with an effective means of reaching these audiences.

A company advertising on television can incur excess marketing costs as a result of most TV programming being directed towards the public at large, some of which may be out of the advertisers specific target market. Consequently, the advertiser is paying a premium to reach an unresponsive portion of the audience. With up to 100 channels of CDR system programming available in markets throughout the world, an advertiser will be able to identify effectively and economically the audience its wishes to reach through a process in radio broadcasting known as narrowcasting. In narrowcasting, programming is geared to the specific tastes of a homogeneous groups with similar interests. These groups can be identified in age, gender or ethnic segments. Examples of segments would be Hispanic communities, elderly, financial/business audiences, etc.. There are an average of six television stations per market operating throughout the country. For the most part, television stations offer little diversity in overall programming to viewers of various backgrounds because they must appeal to a much broader audience. With 100 channels of CD Radio available in every market, certain national broadcasters will have the flexibility to tailor their program material specifically to the preferences of their target audiences. Narrowcasting on a national basis could enable the broadcaster to reach massive audiences with high quality program material not available on a local level and also allow the advertiser to efficiently manage its marketing budget.

Quantitative Analysis

While national advertisers certainly have not fully utilized radio in their marketing strategies, they have not ignored it either. According to the Radio Advertising Bureau, national advertisers have spent well over a billion dollars in radio advertising in each of the past three years:

1989	$1,530,000,000
1988	$1,402,000,000
1987	$1,315,000,000

Multiplying the 1989 total by the average annual increase of approximately 8%, the current year national advertising total should be in the $1.65 billion range. Based on the revolutionary capabilities provided by the CD Radio system as discussed in this document, it is reasonable to conclude that future national radio advertising revenues will reach historic levels. The following schedule approximates future revenues for users of the CD Radio system:

Approximte existing national radio advertising	1,600,000,000
Estimated growth factor	150%

Estimated anuual national advertising	2,400,000,000
CD Radio Penetration	50%

Available revenues	800,000,000
Number of CD Radio channels	200

Revenue per channel	4,000,000
	============

The potential future revenues available to the CD Radio system users can be even greater. As already pointed out, the advantages of a national radio broadcast will cause businesses marketing their products and services country wide to review overall marketing strategies. This situation will surely expand radio advertising revenues making national radio broadcasting a very profitable venture.

Satellite CD Radio, Inc.
Petition For Rulemaking
May 18, 1990

Appendix 2

Propagation Analysis for Satellite Sound Broadcasting Systems

APPLICATION OF CODING AND DIVERSITY TO UHF SATELLITE SOUND BROADCASTING SYSTEMS[1]

John E. Miller
ORI, Inc.
Landover, MD 20785

ABSTRACT - Sound broadcasting to fixed, portable, and vehicular receivers using transmissions from geostationary satellites has been under study in several countries since the late 1970s. The early studies were undertaken in preparation for the 1979 General World Administrative Radio Conference in anticipation of securing a frequency allocation for the service somewhere in the portion of the radio frequency spectrum extending from 500 MHz to 2000 MHz. These studies assumed the use of analog frequency modulation techniques and simple receivers, assumptions that led to feasible designs for systems that would provide a medium quality service to fixed, portable, or vehicular receivers operating in environments having little shadowing of the line-of-sight propagation path from the satellite. However, link margins of 30 dB or more were required for urban paths experiencing heavy shadowing. With margins of this magnitude, the practicality of a satellite sound broadcasting system was questioned as the required satellite e.i.r.p. increased to over 80 dBW per channel.

This paper presents the results of a study of alternative means by which to reduce the required link margins in a satellite sound broadcasting system, thus improving the economic feasibility of the service and increasing the possibility of sharing a radio frequency allocation with terrestrial services. Propagation models are presented that account for the effects of shadowing and multipath in the operating environments.

Comparisons are made of the performance that results using time, frequency, and space diversity to moderate the effects of shadowing and multipath for vehicular and portable receivers. It is shown that space diversity has the broadest applicability in restoring the channel performance that would otherwise be degraded by Rayleigh fading channels and by quasi-stationary AWGN channels.

The use of space diversity minimizes the effects of Rayleigh fading over the vehicular propagation path in rural, suburban, and urban environments without requiring all receivers to use space diversity in order to receive the sound channel. Thus, a satellite sound broadcasting system designed around the use of space diversity permits the design and manufacture of an assortment of less complex and less expensive consumer receivers containing only those features necessary for proper operation in the environment for which it is intended. Space diversity may easily be applied to vehicular receivers, as well as portable receivers, and used with either simple analog FM systems or with the more complex digital systems.

Example link budgets are given for candidate satellite sound broadcasting system designs that use analog FM and digital modulation techniques. On the basis of the relative satellite transmitter power required and the flexibility required to design a receiver that operates satisfactorily in its intended environment, space diversity provides the most cost-effective means by which to implement a satellite sound broadcasting service that uses either analog FM or digital modulation techniques.

I. INTRODUCTION

There is international interest in developing a satellite sound broadcasting service in which medium- to high-quality sound programs transmitted from a geostationary satellite may be received by the general public possessing consumer quality fixed, portable, and vehicular receivers. Studies assessing the general feasibility of the service, the range of preferred system parameters, and the preferred operating frequency band date back to the early 1960s. The timing of these studies tend to coincide with preparations for international administrative radio conferences that are competent to allocate portions of the spectrum to the service. Suffice it to say that after a series of such conferences, there is yet to be spectrum allocated for satellite sound broadcasting. The latest round of studies began about 1977 in preparation for the 1979 General World Administrative Radio Conference (WARC-79) and has continued as two succeeding conferences have dealt with the issue [1]-[6].

Several administrations submitted proposals concerning satellite sound broadcasting to the WARC-79. The Conference considered these proposals and, though unable to make a suitable allocation to the service, did adopt Resolution 505, which [7]: a) encouraged administrations to carry out sound broadcasting experiments within the band 0.5 GHz to 2.0 GHz; b) requested the CCIR to expedite studies of the technical and operating characteristics of the service and the feasibility of sharing with terrestrial services; and c) authorized the next competent WARC to take appropriate actions regarding an allocation for satellite sound broadcasting, including the possible development and approval of procedures to protect and re-accommodate in other bands assignments to stations in the terrestrial services that may be affected by allocations to a sound broadcasting service.

The 1985 WARC-ORB(1) (a conference concerned with the geostationary satellite orbit and the services utilizing it) was the next competent WARC to consider the satellite sound broadcasting question. It decided that further studies by the CCIR were required and deferred the question of an allocation to the second session of the Conference (WARC-ORB(2)), which was held from 29 August to 5 October 1988.

WARC-ORB(2) considered both the results of the CCIR studies and a proposal submitted by one administration. The Conference decided, in Resolution COM5/1, that the possibility of an allocation to the Broadcasting-Satellite Service (Sound) (BSS (Sound)) should be considered at a future allocations conference dealing with the mobile services (including the mobile-satellite service) and with frequencies in the range 500 MHz to 3000 MHz. This conference will probably be scheduled for 1992. Thus, definitive regulatory action on an international scale must await the next allocations conference.

The technical studies referred to above, plus studies summarized in CCIR Report 955-1 [8] (which is devoted to satellite sound broadcasting), assume the use of analog frequency modulation (FM) sound transmission techniques with characteristics comparable to those used in conventional VHF/FM broadcasting service. Adopting this technology

1. This work was partially supported by the Voice of America.

permits the reception of satellite sound broadcasts by the addition of a simple, low-cost frequency converter to the front end of a conventional VHF/FM receiver.

Table I (from [8]) provides a summary of the technical and operating characteristics of relatively simple FM satellite sound broadcasting systems required to provide four different grades of service to vehicular receivers. The standard "A" service referred to in the table applies to a rural area with a relatively high elevation angle of 70°. The margin is based on ensuring that the receiver threshold is exceeded over at least 90% of the area.

Standard "B" applies to an urban area receiving at a relatively low elevation angle of 20°. The margin is sufficient to ensure that the vehicular receivers will operate above threshold over 90% of the area.

Standard "C" also applies to reception in an urban area at a relatively low elevation angle. In this case the margin is such that the vehicular receiver will be operating above threshold for 90% of the time over 90% of the area.

Standard "D" also applies to reception in an urban environment except that the margin is set such that the vehicular receiver will be operating above threshold for 90% of the time over 95% of the area.

The studies referenced above have generally concluded that currently available satellite technology is capable of providing a satellite sound broadcasting service given an appropriate allocation in a portion of the spectrum extending from about MHz to 3000 MHz. However, as shown in Table I, simple analog FM systems (and by extension, simple digital systems) require a rather high satellite e.i.r.p. to serve reliably the vehicular receiver with only a moderate quality sound broadcasting service. The need for high power increases the cost of the satellite and decreases the possibility of sharing an allocation with terrestrial services. However, the implementation of coding and diversity techniques can mitigate these problems.

The purpose of this paper is to examine the use of coding for digital sound transmission techniques and the use of diversity techniques for both analog FM and digital transmission methods. Using coding and diversity, where appropriate, will [6]:

a) reduce the e.i.r.p. required from the satellite, thus reducing the cost of the satellite,

b) reduce the effects of fading on the sound quality produced by fixed, portable, and vehicular receivers, and,

c) permit reduced spectral power flux density on the surface of the earth, thus facilitating sharing between the BSS (Sound) and terrestrial services.

II. PROPAGATION FACTORS

This section describes the propagation factors affecting the design and performance of the example system designs given in Section V.

Service to receivers in three operating environments are considered in Section V: Case 1) a portable receiver operating inside a house that is not shadowed by trees; Case 2) a vehicle operating in a rural environment that is devoid of significant multipath and shadowing by foliage, and Case 3) a vehicle operating in a rural environment that exhibits significant multipath and shadowing by foliage. Each of these environments exhibits a somewhat different type of propagation path.

A. Fixed and Portable Receiver Propagation Factors

For fixed and portable receivers operated within houses or other types of buildings (Case 1), allowance must be made for absorption and scattering of the signal due to walls, ceilings, and roofs [5]. Measurements of the mean signal within single family dwellings were made at 860 MHz, 1550 MHz, and 2569 MHz using the Application Technology Satellite 6 (ATS-6). These measurements have shown that the penetration loss is a function of frequency, receiving antenna polarization, construction of the house (wood siding or brick veneer), the extent of thermal insulation within the house (ceilings and walls), and the proximity of the room to an outside wall [9]. Penetration loss was found to be virtually independent of elevation angle down to 5 degrees for paths not obstructed by trees or other buildings. The distribution for the penetration loss for each type of house was found to be closely approximated by the normal distribution with a standard deviation (including the random measurement error of about 1.5 dB) of 3 dB.

For the portable radio example analyzed in Section V, it is assumed that the receiver is operated in an inside room of a fully insulated brick veneer house. For an operating frequency of 1000 MHz, the mean penetration loss is 8 dB. To account for the variability in 90% of the houses of this type, an additional 4 dB is added. The resulting 12 dB excess path loss applies to houses of the particular construction assumed, which is assumed not to be shadowed by other buildings or trees. For houses with interior walls and ceilings constructed using gypsum wallboard backed by aluminum foil, the average penetration loss will increase to over 17 dB. Similarly, for houses surrounded by large trees, an additional loss of 12-15 dB at 1000 MHz is appropriate.

B. Vehicular Receiver Propagation Factors

Impairments on the propagation path between the satellite and the vehicular receiver can affect the system performance in a significant way. Early measurements made using ATS-6 [10] indicated that the small-scale variations in the signal power received by a vehicle (i.e., as measured over distances of several hundred wavelengths) could be statistically characterized by the sum of a constant signal and an independent Rayleigh- distributed variate. The probability density function for the envelope of the sum of these variates is given by the well-known Rician distribution. Over a large distance (i.e., a distance in excess of several hundreds of wavelengths) it was found that the distribution of the mean e of the received signal power could be approximated by log-normal density function. The log-normal variate accounted for the mean variation in the line-of-sight (LOS) signal due to foliage and building attenuation; the Rayleigh component accounted primarily for the effects of diffuse scattering from the ground and nearby objects. Recent measurements confirm the general validity of this model [11]-[13].

Propagation data taken at about 800 MHz in a rural area from a simulated satellite-to-mobile link are shown in Figure 1. These data were taken at an elevation angle of 15 degrees along roads with clear LOS paths (curve d) and with paths obstructed by foliage (curve b) [14]. Also shown on the figure are two curves corresponding to the Rayleigh distribution with a 10 dB mean excess path loss (curve a) and the Rayleigh distribution with 0 dB mean excess path loss (curve c). For a lightly shadowed path (curve d), the Rayleigh curve provides a very conservative lower bound on the fading statistics. However, for a heavily shadowed path (curve b), the Rayleigh curve provides a very adequate characterization of the fading statistics. Therefore, the Rayleigh distribution with a suitably selected value for the mean excess path loss provides a practical lower bound on the statistical distribution of the envelope of the received signal.

Based on the discussion above, the channel model used to pare the link budget given in Section V for a portable ceiver operating inside a single story house is the additive white Gaussian noise (AWGN) channel with an excess path loss of 12 dB. Similarly, the link budgets for vehicles operating in a rural environment are based on the Rayleigh fading channel model. For a rural environment that is essentially free from shadowing of the LOS path by trees and other foliage (Case 2), the mean excess path loss is 0 dB. For rural areas with significant LOS shadowing by trees and foliage (Case 3), the mean excess path loss is 10 dB.

III. FORWARD ERROR CORRECTION CODING

The use of forward error correction coding (FEC) affords a means by which to reduce significantly the required e.i.r.p. for digital satellite sound broadcasting systems. Using FEC improves the possibility of deploying a more economical satellite and increases the possibility for sharing an allocation to the BSS (Sound) with terrestrial services. A rate 1/2, constraint length 7 ($R=1/2$, $K=7$) convolutional code combined with a decoder using the Viterbi maximum likelihood decoding algorithm (VA) offers a significant coding gain when compared to the performance of an uncoded digital link using quadrature phase shift keying (QPSK) modulation and coherent detection.

omparison of the bit error ratio (BER) for a coded and an coded link is shown in Figure 2. Curve (a) applies to a memoryless Rayleigh fading channel employing an $R=1/2$, $K=7$ convolutional code, QPSK with coherent detection, and soft decision decoding using the Viterbi algorithm. Curve (b) is the BER that would be realized over the same link in the absence of coding. As shown in the figure, the code will provide in excess of 36 dB improvement in performance over a memoryless Rayleigh fading channel when compared to an uncoded system at a bit error ratio (BER) of 10^{-5} [15]. This same configuration will provide a coding gain at a BER of 10^{-5} of about 5 dB when compared to an uncoded system over the AWGN channel. Achieving a coding gain of 36 dB using convolutional coding and Viterbi decoding is critical to providing a quality sound program service to the vehicular receiver without requiring excessive e.i.r.p. margins on the link. Coding is not as critical to the performance of the portable receiver. Regardless, the use of a potentially complex Viterbi decoder in a consumer quality receiver is believed to be justified by the availability of several sources for a commercial decoder chip [16]-[18].

IV. DIVERSITY TECHNIQUES

The performance realizable with coding on the fading vehicular channel is dependent on the statistical characteristics of the fading. On channels where the fading rate is much less than the symbol rate, the received signal level is essentially constant for the duration of the symbol. Consequently, the received symbol energy of adjacent symbols will tend to be identical, a condition that does not meet the requirement that the channel be memoryless in order to realize a coding gain of 36 dB. If the channel is not memoryless, there is a catastrophic increase in the BER of high-performance convolutional codes when the channel is in a deep fade. There are three primary diversity techniques capable of lessening the effects of deep fades: 1) frequency diversity, 2) time diversity, and 3) spatial diversity. These methods are briefly described below.

A. Frequency Diversity

Frequency diversity uses M carriers, each carrying the same information, spaced in frequency by an amount that equals or exceeds the coherence bandwidth of the channel. A variation of the frequency diversity technique is being studied by the European Broadcasting Union (EBU) for possible application to a digital satellite sound broadcasting system [19],[20]. The method being studied by the EBU is orthogonal frequency division multiplexing (OFDM) [21], which is essentially a parallel data transmission technique. The approach being implemented by the EBU also uses sub-band coding to achieve a bit rate of 250 kbit/s or less per stereo program, a rate 1/2, constraint length 7 convolutional code, 16 carriers per sound program, and QPSK to modulate each carrier. The symbol rate per carrier is 16.625 kBaud with 250 kHz spacing between carriers belonging to the same program. Fifteen other sound program channels are interleaved with this channel, resulting in a total of 256 carriers spaced 15.625 kHz in a total bandwidth of 4 MHz to transmit 16 sound programs [20].

To obtain independent fading of the carriers with the use of frequency diversity requires that the delay spread of the channel exceed some minimum value. For a channel characterized by an exponential distribution of the delay (typical of a terrestrial path), the mean value of the delay spread must be greater than the reciprocal of the program carrier spacing [22]. If this minimum value is not realized, then fading on the channel will tend towards flat fading, and the actual coding gain will be less than expected. For this reason, frequency diversity is most suitable for use in heavily shadowed urban areas where the mean delay spread will be the greatest. The mean delay spread in a rural environment will be less than that of an urban environment. Measurements on a simulated space-to-Earth path in a rural environment indicates that the coherence bandwidth is in excess of 4 MHz (implying a mean delay spread on the order of 0.25 us) [23]. By comparison, the mean delay spread on a terrestrial path in an urban area is on the order of 1.3 us [22]. Consequently the spacing of the carriers used for frequency diversity must be greater in a rural environment.

B. Time Diversity

The second method is based on time diversity. One means by which to implement this technique for a digital system is to interleave the transmitted symbols and to deinterleave the received symbols in a prescribed manner [24]. By introducing a sufficient amount of delay in the interleaver, symbols that were adjacent prior to interleaving are, after interleaving, separated in time by an amount greater than the correlation time of the channel. Performance of a convolutional code is thus restored by separating the symbol error patterns so that symbol errors do not occur in long bursts. This method, which has been studied for application to satellite sound broadcasting [25], is most effective for vehicular channels which exhibit relatively rapid fading. Time diversity requires that an impractical amount of digital memory be installed in the receivers in order to restore the coding gain on channels exhibiting very slow fading. For these reasons, time diversity does not appear to be a practical approach for either a digital system or for an analog FM system.

C. Spatial Diversity

Spatial diversity is based on the use of multiple receiving antennas. The antennas must be spaced sufficiently far apart so that the received signals fade independently. For a terrestrial mobile communication path, the required spacing is on the order of one-half wavelength or greater [22]. Comparable spacings have been found on space-to-Earth paths [10].

The independently fading signals at the output of each antenna may be combined to form an output signal whose fading depth is significantly less than the fading depth of the individual signals. One combining method is maximum-ratio combining. And one implementation of this method uses M phase-locked loops to bring the signals at the output of M antennas into phase coherence. The signals are then amplitude weighted and summed to form a composite signal [22]. Maximal-ratio combining may be used for either digital or analog signals.

For a digital system, the probability of error (P_e) on a Rayleigh fading convolutionally coded link, received with an M-branch spatial diversity, maximal-ratio combining receiver and a Viterbi decoder is given by [15]

$$P_e = \int_0^\infty \frac{\gamma_r^{M-1}\, \varepsilon^{-(\gamma_r/\Gamma)}}{\Gamma^M\, (M-1)!}\, P(\gamma_r)\, d\gamma_r \qquad (1)$$

$$P(\gamma_r) = \varepsilon^{(\alpha_o-\alpha_1\gamma_r)}, \quad \gamma_r > \frac{\ln(2) + \alpha_o}{\alpha_1} \qquad (2a)$$

$$P(\gamma_r) = 1/2, \quad \gamma_r < \frac{\ln(2) + \alpha_o}{\alpha_1} \qquad (2b)$$

$$\alpha_o = 4.4514 \qquad (3a)$$

$$\alpha_1 = 5.7230 \qquad (3b)$$

where,

γ_r = instantaneous bit-energy-to-noise density ratio (numeric),

M = order of diversity, and,

Γ = mean branch bit-energy-to-noise density ratio (numeric).

Equation (2) applies specifically to an optimal R=1/2, K=7 convolutional code [26].

Equation (1) has been evaluated with the results shown in Figure 3. Curve (a) of the figure shows the BER for 4th order spatial diversity with maximal-ratio combining. It is seen that 4th order diversity with a mean bit-energy-to-noise density ratio per branch of about 7.0 dB achieves a BER=10^{-5}. This value is used in the link budget for the example vehicular receiver in Section V.

Figure 3 also shows the BER for an R=1/2, K=7 convolutional code received over an AWGN channel (curve b) and over a memoryless Rayleigh fading channel (curve c). Coherent detection of a QPSK carrier in combination with VA decoding was assumed in both cases.

Spatial diversity with maximal-ratio combining may also be used for satellite sound broadcasting systems employing analog FM modulation techniques. In a Rayleigh fading environment, the probability density function of the instantaneous received carrier power relative to the mean carrier power per branch for an M-branch maximal-ratio combiner is given by [22]

$$P(\gamma) = \frac{1}{(M-1)!}\, \frac{\gamma^{M-1}}{\Gamma^M}\, \varepsilon^{(-\gamma/\Gamma)} \qquad (4)$$

and the probability distribution function for the M-branch combiner is given by

$$P(\gamma \le X) = 1 - \varepsilon^{(-X/\Gamma)} \sum_{k=1}^{M} \frac{(X/\Gamma)^{k-1}}{(k-1)!} \qquad (5)$$

where,

γ = the instantaneous carrier power at the output of the combiner (numeric),

M = order of diversity, and,

Γ = mean carrier power per branch (numeric).

Equation (5) is plotted in Figure 4 for M=1 to M=4. The figure illustrates the reduction of the fading depth of the received carrier power, at a prescribed probability, for an M-branch spatial diversity and maximal-ratio combining. As illustrated in the figure, the improvement is about 26 dB at the 0.001 probability level for a 4-branch system when compared to no diversity in a Rayleigh fading environment.

V. EXAMPLE SYSTEMS

Two example satellite sound broadcasting systems have been considered: 1) a digital system capable of providing a high-quality service, and 2) an analog FM system capable of providing a medium quality service.

The example link calculations given in Tables II and III assume a somewhat higher receiving antenna gain and a lower receiving antenna system noise temperature than the values assumed in Table I. Further, the link calculations are based on an operating frequency of 1000 MHz in order to be consistent with example systems described in the literature. The results may, however, be easily scaled to other operating frequencies ꞏe range 500 MHz to 3000 MHz.

A. Digital System (Case 1)

The significant characteristics of an example digital satellite sound broadcasting system are given in Table II. Adaptive delta modulation (ADM) has been selected in view of: 1) the performance achieved at moderate sampling rates and channel error rates, and 2) the availability of a low cost decoder chip set [27]. At a bit rate of 220 kbit/s per stereo sound channel (440 kbit/s for a stereo program channel), ADM achieves a measured signal-to-noise ratio (SNR) of at least 58 dB in a 15 kHz baseband and a dynamic range of 85 dB [28]. Subjectively, a BER less than 10^{-5} corresponds to an impairment rating greater than 4.5 on a 5.0 point scale. (An impairment rating of 4 indicates a perceptible, but not annoying, degradation in the sound quality, whereas an impairment rating of 5 indicates an imperceptible degradation in the sound quality [29].)

An R=1/2, K=7 convolutional code is used for FEC in conjunction with QPSK and coherent demodulation at the receiver.

The performance given in Table II for the portable receiver operating inside a house is based on the assumption that a VA decoder is used. It should be noted however that it is not ꞏlutely necessary that a VA decoder be included in all ꞏable receivers. For example, a home receiver with an outdoor antenna would need only a simple decoder that should cost less than a receiver with a VA decoder.

The vehicular receiver is potentially the most complex receiver since it must operate in the most difficult environment. The performance given in Table II is based on the use of quad-spatial diversity (four receiving antennas spaced a half-wavelength or more apart), maximal-ratio combining, and a full implementation of a decoder using the Viterbi maximum likelihood algorithm.

From the results given in Table II, it is seen that the use of ADM and convolutional coding provides a very high (Q=4.5) sound quality as received by fixed, portable, and vehicular receivers operating in a satellite sound broadcasting system. Reference to Table I will show that this performance is achieved at a lower e.i.r.p. and lower spectral power flux density than previously studied FM systems [1]-[6]. Thus, the possibility of sharing between the BSS (Sound) and terrestrial services should be enhanced. Further, the economic feasibility of satellite sound broadcasting is improved since a lower per channel e.i.r.p. is required. This will generally mean that the space segment investment cost for a coded ADM system will be less than that for a comparable FM or uncoded digital system.

B. Analog FM System (Case 2)

The link budget for an example analog FM system is shown in Table III. Service is to a vehicular receiver operating in a lightly shadowed and also in a heavily shadowed rural area. The receiving system uses quad-spatial diversity and maximal-ratio combining to minimize the effects of Rayleigh fading. An operating margin of 3.5 dB above a 10 dB threshold has been used which corresponds to a probability of 0.001 that the signal will fade below the threshold. (Listening tests are needed to verify the suitability of this margin.)

Comparing the general results given in Table I with those given in Table III shows that quad-spatial diversity with maximal-ratio combining provides a significant means to reduce the satellite e.i.r.p. required to adequately serve a vehicular receiver. A reduction of over 26 dB is possible based on the criterion that the probability of fading below threshold must be less than 0.001 in a Rayleigh fading environment.

VI. SUMMARY AND CONCLUSIONS

The vehicular receiver operating in an environment in which the space-to-Earth propagation path is characterized as a heavily shadowed Rayleigh fading channel imposes the most severe requirements on the design of a satellite sound broadcasting system. In prior studies, these conditions have been accounted for by either adding large link margins or by using channel coding methods that require a high level of complexity to be built into all receivers, regardless of the environment in which they are intended to operate. The consequence of using this approach has resulted either in the need for satellites with excessive e.i.r.p. (which increases the cost and risk associated with the service) or in the imposition of a high level of receiver complexity. In order to advance the commercial feasibility of a satellite sound broadcasting service, it would be desirable to minimize the e.i.r.p. required from the satellite (to reduce cost and risk) and to enable the use of receivers of varying cost and having a level of complexity commensurate with the environment in which they are intended to operate.

It has been shown that the use of quad-spatial diversity with maximal-ratio combining in the vehicular receiver permits a significant reduction in the satellite e.i.r.p. for both digital and analog FM systems. A further reduction is possible with digital systems through the use of an R=1/2, K=7 convolutional code.

It may be pointed out that the system concepts based on the use of quad-spatial diversity and maximal-ratio combining afford the possibility of a range of modular receiver designs. It is further contended that a modular design offers the best opportunity to market cost effective, consumer quality receivers tailored to the particular operating conditions.

REFERENCES

[1] C. Rosetti and H-H. Fromm, "Possibilities for National Coverage by FM Sound Broadcasting from Satellites in Certain Parts of the Frequency Spectrum," EBU Review - Technical Part, April 1977.

[2] F. Guilbeau, "Satellite Sound Broadcasting on Frequencies of About 1 GHz. Simulation of Transmission and Urban Reception," EBU Review - Technical Part, No. 176, pp. 174-178, August 1979.

[3] C. Rosetti and H-H. Fromm, "UHF Radio Broadcasting by Satellite," presented at the AIAA 8th Communications Satellite Systems Conference, Orlando, FLA, April 20-24, 1980.

[4] J. Chaplin, C. Rosetti, and H-H. Fromm, "Broadcasting of Sound Radio Programmes by Satellite Direct to Portable and Vehicle Receivers: A Proposal for Africa," Space Communication and Broadcasting, Vol. 2, No. 1, pp. 3-11, March 1984.

[5] J.E. Miller, "Satellite Sound Broadcasting Around 1 GHz," IEEE Journal on Selected Areas in Communications, Vol. SAC-3, No. 1, pp. 204-210 January 1985.

[6] J.E. Miller, "Technical Possibilities of DBS Radio At or Near 1 GHz," Proceedings of the 15th International Television Symposium and Technical Exhibition, Montreux, Switzerland, pp. 387-405, June 1987.

[7] "Radio Regulations, Edition of 1982," International Telecommunications Union, Geneva, Switzerland, 1982.

[8] "Satellite Sound Broadcasting with Portable Receivers and Receivers in Automobiles," CCIR Report 955-1, Vols. X and XI, Part 2, XVI Plenary Assembly, Dubrovnik, 1986, pp. 107-128.

[9] P.I. Wells, "The Attenuation of UHF Radio Signals by Houses," IEEE Transactions on Vehicular Technology, Vol. VT-26, No. 6, pp. 358-362, November 1977.

[10] G.C. Hess, "Land-Mobile Satellite Excess Path Loss Measurements," IEEE Transactions Vehicular Technology, Vol. VT-29, No. 2, pp. 290-297, May 1980.

[11] J.S. Butterworth and E.E. Matt, "The Characterization of Propagation Effects for Land Mobile Satellite Services," IEE Proceedings of Satellite System Mobile Communication and Navigation Conference, June 1983.

[12] C. Loo, "Measurements and Models of a Land Mobile Satellite Channel and Their Applications to MSK Signals," IEEE Transactions on Vehicular Technology, Vol. VT-35, No. 3, pp. 114-121, August 1987.

[13] J. Goldhirsh and W.J. Vogel, "Roadside Tree Attenuation Measurements at UHF for Land Mobile-Satellite Systems," IEEE Transactions on Antennas and Propagation, Vol. AP-35, pp. 589-596, May 1987

[14] C. Loo, "A Statistical Model for a Land Mobile Satellite Link," IEEE Transactions on Vehicular Technology, Vol. 34, No. 3, pp. 122-127, August 1985.

[15] J.G. Proakis, Digital Communications, McGraw-Hill Book Co. New York, London, 1983.

[16] "Qualcomm Announces Single-Chip K=7 Viterbi Decoder Device," IEEE Communications Magazine, April 1987, Vol. 25, No. 4, page 75.

[17] "Preliminary Data Sheet for 1HD18 VHSIC Convolutional Decoder (CD)," TRW Military Electronics Division, One Space Park, Redondo Beach, California 90278, 1985.

[18] "Preliminary Specifications, VLSI/VHSI K=7 Viterbi Codec," Harris Corporation, Government Systems Sector, Washington Office, Washington, D.C. 20037, 1984.

[19] D. Pommier, and Y. Wu, "Interleaving or Spectrum-Spreading in Digital Radio Intended for Vehicles," EBU Review - Technical Part, No. 217, June 1986.

[20] R.J. Levey, editor, "Advanced Digital Techniques for UHF Satellite Sound Broadcasting," Published by the EBU Technical Center, Bruxelles, Belgium, August 1988

[21] S.B. Weinstein, and P.M. Ebert, "Data Transmission by Frequency-Division Multiplexing Using the Discrete Fourier Transform," IEEE Transactions on Communication Technology, Vol. COM-19, No. 15, October 1971.

[22] W.C.Y. Lee, Mobile Communications Engineering, McGraw-Hill Book Co., New York, London, 1982.

[23] R.J.C. Bultitude, "Measured Characteristics of 800/900 MHz Fading Radio Channels with High Angle Propagation Through Moderately Dense Foliage," IEEE Journal on Selected Areas in Communications, Vol. SAC-5, No. 2, pp. 116-127, February 1987.

[24] G.C. Clark, Jr. and J.B. Cain, Error-Correction Coding for Digital Communications, Plenum Press, New York and London, 1981, pp 345-352.

[25] "Contribution to Section 4.3 (Systems Characteristics) of JIWP 10-11/1 Report: The Use of Digital Technology for Satellite Sound Broadcasting in Band 9," Document US JIWP 10-11/1-1 (Rev. 3), 16 April 1986.

[26] J.H. Yuen, editor, Deep Space Telecommunications Systems Engineering, JPL Publication 82-76, 1982.

[27] "Data Sheet for NE5240 Dolby Digital Audio Decoder," Signetics, Sunnyvale, California, 1985.

[28] "Deltalink Digital Audio System," Information Sheet S85/6731, Dolby Laboratories, San Francisco, CA 94111.

[29] "Subjective Assessment of Sound Quality," CCIR Recommendation 562-2, Vol. X, Part 1, XVI Plenary Assembly, Dubrovnik, 1986, pp. 275-279.

TABLE I

LINK BUDGET FOR A UHF ANALOG FM SATELLITE SOUND BROADCASTING SYSTEM [8].

System parameter	Standard of service			
	A	B	C	D
Type of modulation	FM			
Carrier deviation (kHz)	±75			
Noise bandwidth (kHz)	250			
Carrier-to-noise ratio (dB)	10			
Coupling loss (dB)	1			
Receive antenna gain (dBi)	3			
Receive system noise temp.(K)	2000			
Carrier frequency (MHz)	1000			
Link margin (dB)	6	15	25	33
LOS pfd at beam edge ($dB(W/m^2)$)	-106.4	-97.4	-87.4	-79.4
Equivalent field strength at beam edge (dB(uV/m))	39.4	48.4	58.4	66.4
Maximum spreading loss (δ=17 deg.) (dB/m^2)	-163.0	-163.0	-163.0	-163.0
Beam-center e.i.r.p. (dB(W))	59.6	68.6	78.6	86.6
Satellite antenna gain (D=20 m) for 1 deg. BW (dBi)	43.9	43.9	43.9	43.9
Antenna input power (dB(W))	15.7	24.7	34.7	42.7
Antenna input power (W)	37	295	2951	18621

TABLE II

LINK BUDGET FOR A DIGITAL SATELLITE SOUND BROADCASTING SYSTEM USING CONVOLUTIONAL CODING, VA DECODING, AND QUAD-SPATIAL DIVERSITY ON THE VEHICLE.

System parameter	Value
Type of modulation	QPSK
Primary reception mode	stereophonic
Bit rate (kbit/s)	440
Code rate	1/2
Modulation rate (kBaud)	440
Required RF Bandwidth (kHz)	880
Received SNR (dB)	58
Subjective sound impairment	Q=4.5
Received bit error ratio	10^{-5}
Audio bandwidth (kHz)	15
Carrier frequency (MHz)	1000

Receiving environment	Vehicular		House
	Light foliage	Heavy foliage	
Receiver antenna gain (dBi)	5.0	5.0	5.0
Coupling loss (dB)	1.0	1.0	1.0
Receiver system noise temp.(K)	600	600	600
Required E_b/N_o (dB)	7.0	7.0	3.8
Implementation margin (dB)	1.0	1.0	1.0
Mean excess path loss (dB)	0	10.0	12.0
LOS pfd at beam edge (dB(W/m^2)	-119.0	-109.0	-110.2
Equivalent field strength at beam edge (dB(uV/m))	26.8	36.8	35.6
Maximum beam-center pfd per 4 kHz (dB(W/m^2/4kHz))	-136.1	-126.1	-127.3
Maximum spreading loss (δ=17 deg.) (dB/m^2)	-163.0	-163.0	-163.0
Beam-center e.i.r.p. (dBW)	47.0	57.0	55.8
Satellite antenna gain (D=20 m) for 1 deg. BW (dBi)	43.9	43.9	43.9
Antenna input power (dB(W))	3.1	13.1	11.9
Antenna input power (W)	2.0	20.4	15.5

TABLE III

LINK BUDGET FOR AN ANALOG FM SATELLITE SOUND BROADCASTING SYSTEM SERVING A VEHICULAR RECEIVER USING QUAD-SPATIAL DIVERSITY AND MAXIMAL RATIO COMBINING.

System parameters	Value	
Type of modulation	FM	
Primary reception mode	Monophonic	
Carrier deviation (kHz)	± 75	
Noise bandwidth (kHz)	250	
Carrier-to-noise ratio (dB)	10.0	
Signal-to-noise ratio (dB)	40.0	
Coupling loss (dB)	1.0	
Receiver antenna gain (dBi)	5.0	
Receiver system noise temperature (K)	600	
Carrier frequency (MHz)	1000	
Probability of fading below threshold	0.001	
Margin above 10 dB threshold (dB)	3.5	
Receiving environment	Light foliage	Heavy foliage
Mean excess path loss (dB)	0	10.0
LOS pfd at edge of beam (dB(W/m^2))	-115.9	-105.9
Equivalent field strength (dB(uV/m))	29.9	39.9
Maximum beam-center pfd per 4 kHz (no energy dispersal) (dB(W/m^2/4 kHz))	-115.9	-105.9
Maximum spreading loss (δ=17 deg.) (dB/m^2)	-163.0	
Beam-center e.i.r.p. (dBW)	50.1	60.1
Satellite antenna gain (D=20 m) for 1 degree beamwidth (dBi)	43.9	
Antenna input power (dBW)	6.2	16.2
Antenna input power (W)	4.2	41.7

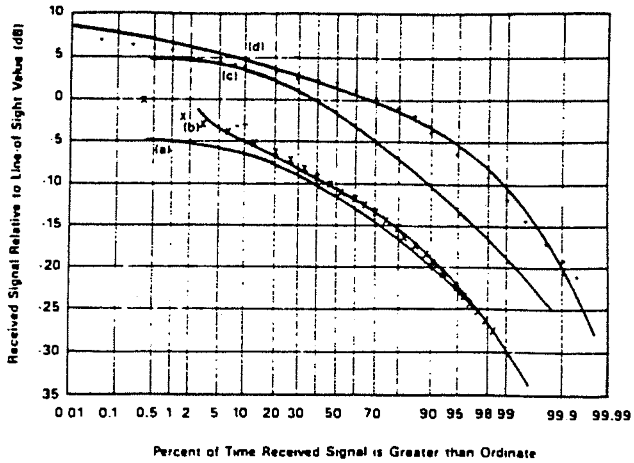


Fig. 1. Measured and calculated probability distribution for the envelope of the received signal. Curve (a) is a Rayleigh distribution with 10 dB excess path loss, curve (b) is the measured distribution in a heavily shadowed rural environment, curve (c) is a Rayleigh distribution with 0 dB mean excess path loss, and curve (d) is the measured distribution in a lightly shadowed rural environment [14].

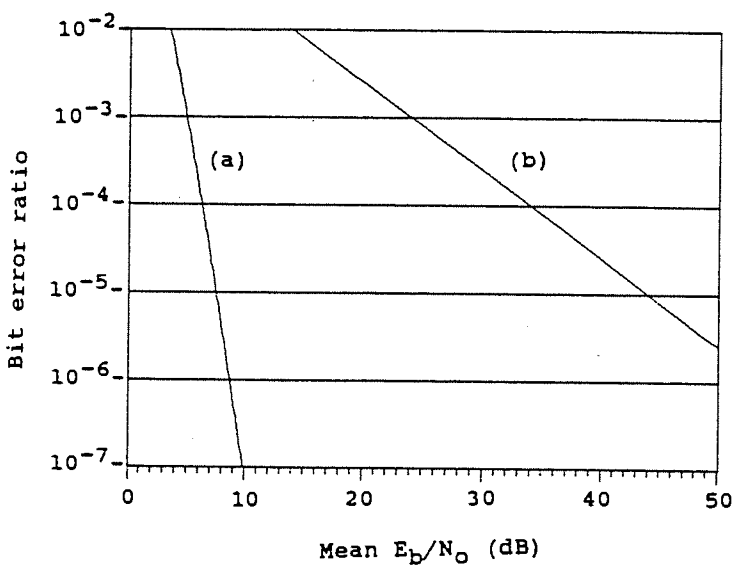


Fig. 2. Performance of coded and uncoded QPSK with coherent detection over a memoryless Rayleigh fading channel. Curve (a) $R = 1/2$, $K = 7$ convolutional code with VA soft-decision decoding, and curve (b) uncoded.

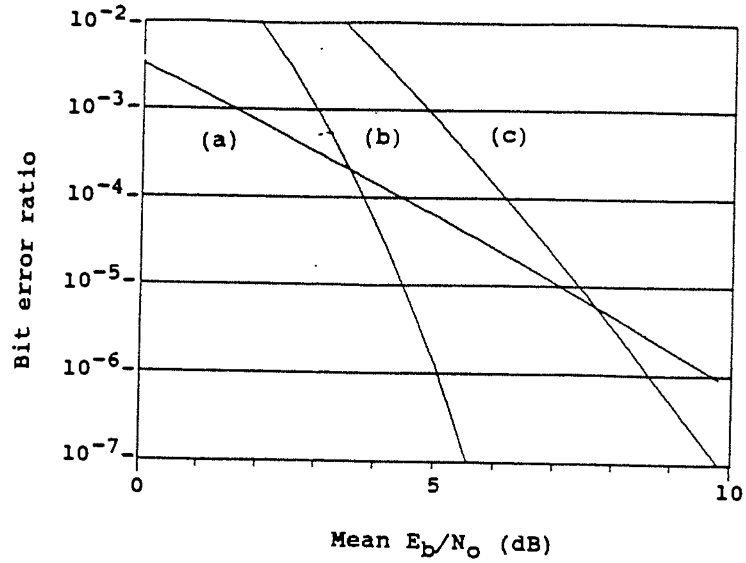


Fig. 3. BER for soft-decision VA decoding of convolutional code; using quad-spatial diversity with maximal-ratio combining on a Rayleigh fading channel with memory (curve (a)), on an AWGN channel (curve (b)), and on a memoryless Rayleigh fading channel (curve (c)).

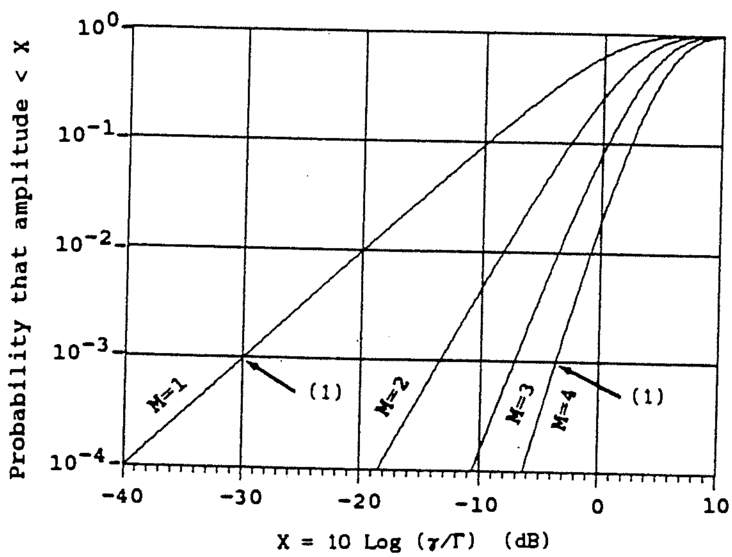


Fig. 4. Performance curves for maximal-ratio combining of independently fading signals. (1) see text.

Appendix 3

CCIR Report 955-1 (MOD F)
"Satellite Sound Broadcasting With
Portable Receivers and Receivers
In Automobiles"

CCIR
XVIIth Plenary Assembly
Düsseldorf, 1990

Document 10-11S/1011-E
15 January 1990

Ref: Document 10-11S/214 Rev. 1

REPORT 955-1 (MOD F)*

SATELLITE SOUND BROADCASTING WITH PORTABLE RECEIVERS AND RECEIVERS IN AUTOMOBILES

(Question 2/10 and 11, Study Programmes 2B/10 and 11, 2K/10 and 11)

(1982-1986)

This report contains:

* This Report should be brought to the attention of Study Groups 5, 8 and 8.

BEFORE THE

Federal Communications Commission

WASHINGTON, D.C. 20554

In the Matter of the Application of SATELLITE CD RADIO, INC. For Authority to Construct, Launch and Operate Space Stations in the Satellite Sound Broadcasting Service	)))))))))	File No.

APPLICATION OF SATELLITE CD RADIO, INC.
FOR A PRIVATE CD QUALITY
<u>SATELLITE SOUND BROADCASTING SYSTEM</u>

Peter Dolan
President

SATELLITE CD RADIO, INC.
Techworld Plaza, Suite 750
Washington, D.C. 20001-8000
(202) 408-0080

May 18, 1990

TABLE OF CONTENTS

BEFORE THE

Federal Communications Commission

WASHINGTON, D.C. 20554

In the Matter of the Application of	)	
SATELLITE CD RADIO, INC.	)	File No.
For Authority to Construct, Launch and Operate a Space Station in the Satellite Sound Broadcasting Service	)	

SATELLITE SYSTEM PROPOSAL

I. INTRODUCTION

Satellite CD Radio, Inc. (hereinafter referred to as "CD Radio, Inc.") is requesting authority to construct, launch and operate two satellites in geostationary orbit providing nationwide digital, CD-quality radio service in the 1470-1530 MHz band.

II. SYSTEM DESCRIPTION

CD Radio, Inc.'s proposed satellite system architecture consists of:

- Two 6000-watt geostationary satellites for U.S. coverage, which are expected to be built by Ford, General Electric, or Hughes, and which will be launched by a launch vehicle construction company such as General Dynamics, Martin Marietta, or McDonnell-Douglas;1/
- An undetermined number of urban-area terrestral repeaters;

1/ The scheduled launch dates are in 1994 and 1995.

- An earth station for feeder links and for telemetry, telecommand and control;
- High-quality terrestrial links (ISDN/optic fiber) for delivery of CD radio programming from various studios to the feeder link earth station;
- Millions of low-cost satellite CD radio receivers in homes, commercial establishments and vehicles.

The proposed system would consist of up to 66 radio stations which would send their CD quality radio programming via high-quality land-lines into CD Radio, Inc.'s feeder link station.2/ At this station, front-end multiplexing equipment will route each incoming phone line into a pre-designated satellite uplink channel. For example, a top radio station in Denver may operate on CD Radio, Inc.'s Channel number 20. In this case, that radio station's programming would immediately be uplinked into Channel 20 upon its receipt at CD Radio, Inc.'s uplink station.

Each of the two satellites in CD Radio, Inc's system will be linked with an operating feeder link transmitting chain (transmitter, antenna, etc.), and will share a back-up chain. The satellites will receive the channels of CD-quality radio programming at 30 GHz (Ka band), amplify the signals, and then beam the channels to earth in the 1470-1530 MHz band.

At the same time the feeder link station beams the

2/ The initial feeder link station will be in Montrose, Colorado.

programming to the satellite, it will send the same programming via wide-band digital links to a network of ground repeaters in urban areas. These terrestrial repeaters will simulcast the satellite signal, i.e. transmit the same channels of CD-quality programming as does the satellite using the same unique Dolby modulation technique, thus compensating as needed for any shadowing in "urban canyons". User radios will automatically select the stronger of the satellite signal or the terrestrial signal carrying the same program. For simplicity, Channel "20" on all three satellite beams of the satellite will also be Channel "20" on the terrestrial repeater, even though the actual frequencies for those transmissions will be different.3/

CD Radio, Inc. proposes to render service on a private carrier basis by selling transponders to both terrestrial broadcasters and to non-broadcasters providing subscription or pay-per-listen services.

III. BASIC APPLICANT INFORMATION

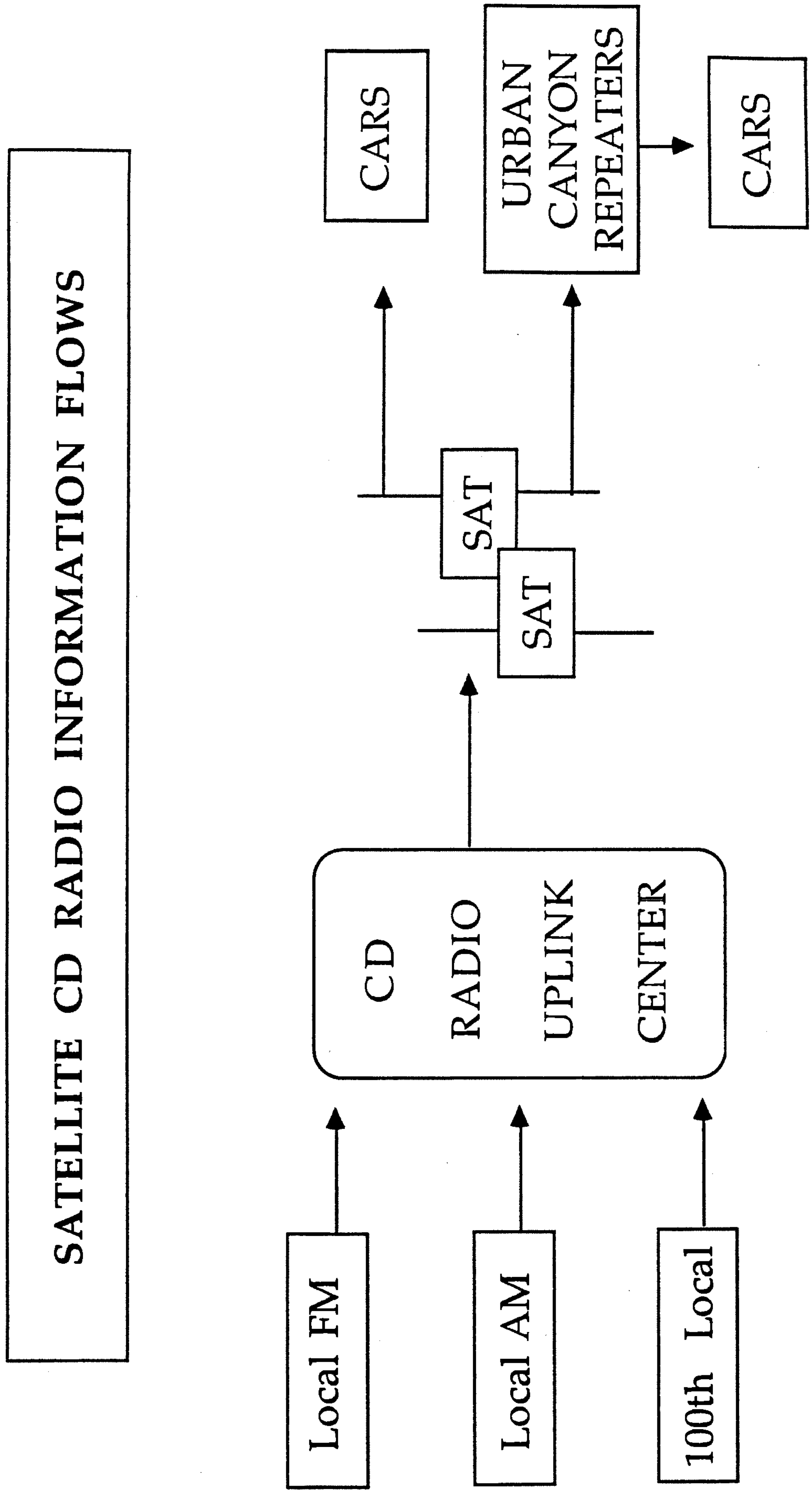
A. Name and Address of Applicant

Satellite CD Radio, Inc.
Techworld Plaza
800 K Street, N.W.
Suite 750
Washington, D.C. 20001

B. Correspondence should be directed to:

3/ The information flow for the satellite CD radio system is schematically described in Figure 1.

Figure 1


SATELLITE CD RADIO INFORMATION FLOWS
Local FM
Local AM
100th Local
CD RADIO UPLINK CENTER
SAT
SAT
CARS
URBAN CANYON REPEATERS
CARS

Peter Dolan
President
Satellite CD Radio, Inc.
Techworld Plaza
800 K Street, N.W.
Suite 750
Washington, D.C. 20001

IV. TECHNICAL QUALIFICATIONS

CD Radio, Inc., is technically qualified to provide the requested service, as evidenced by the technical showing contained in each of the two applications attached to this system proposal, incorporated herein by reference. A highly qualified team of satellite engineers and industry analysts from Stanford Telecommunications, Telecommunication Systems, and MARCOR, Inc., has been assembled to produce a system design which is optimal from both a technical and business standpoint. See Figure 2.

V. FINANCIAL QUALIFICATIONS

The Board of CD Radio, Inc., represents a cross section of successful business interests in the satellite and radio fields. The principals of CD Radio have a track record of successfully financing the projects they undertake.

Capital Costs

Capital outlays for the CD Radio System are $275 million based on a carefully designed project financing structure. Cash

Satellite CD Radio, Inc.
Petition For Rulemaking
May 18, 1990

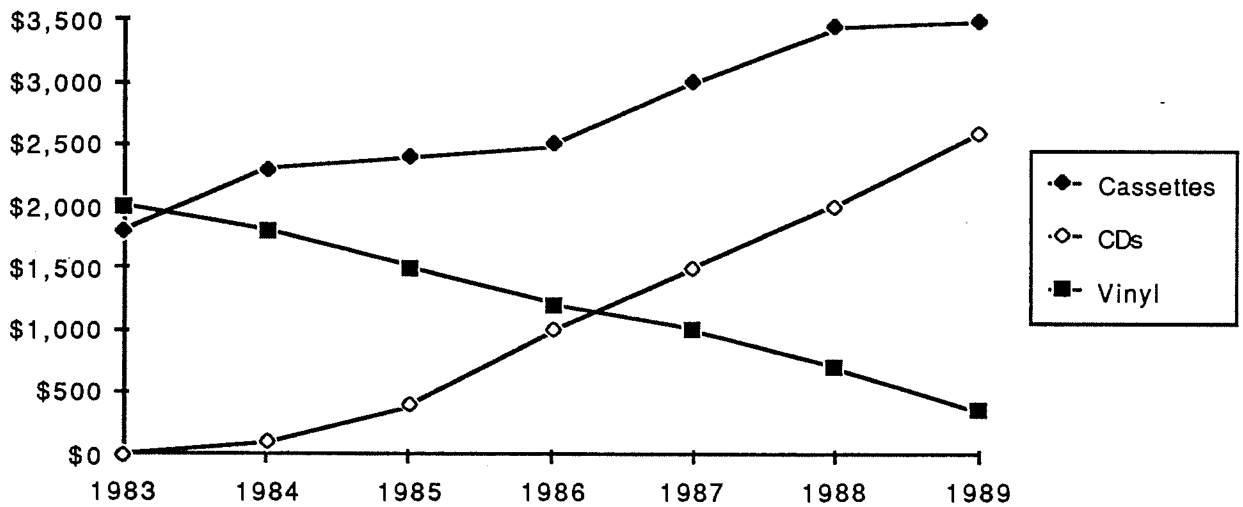
Appendix 1

Analysis of the Market for CD Radio

THE INDUSTRY

With the advent of compact discs, the listening public has become acutely aware of the audio benefits of digital sound. Since compact discs were introduced, its sales have practically eclipsed the existence of vinyl records. The following chart graphically demonstrates the impact of CD's on the recording industry:

RECORDING INDUSTRY SALES
Annual Sales (in millions)

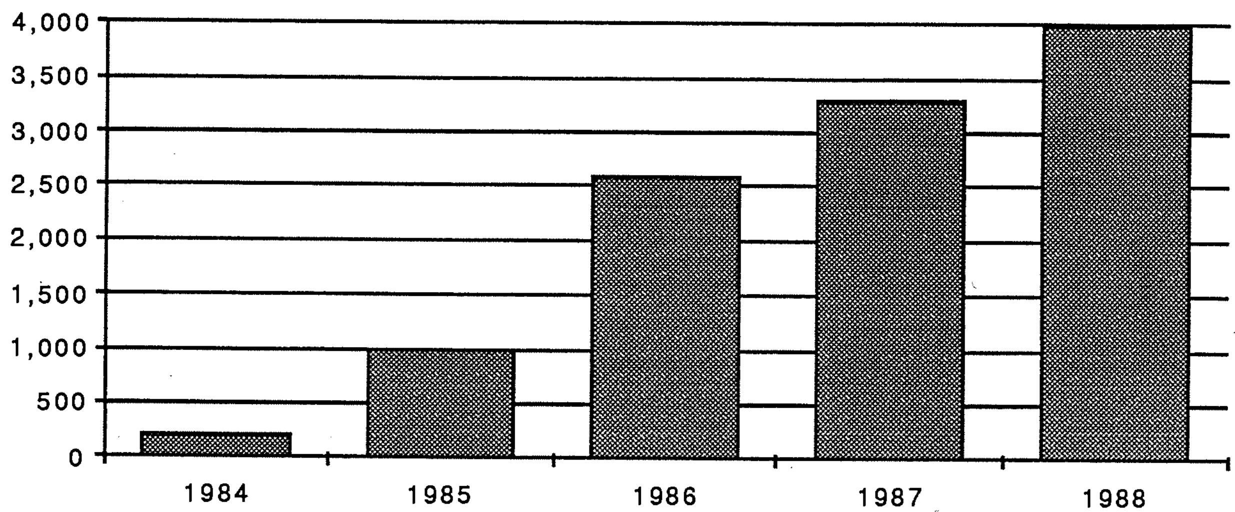


Source: Recording Industry Association

Cassette tape sales have leveled off in recent years and vinyl record sales have declined dramatically over the six year period. Only CD sales have sustained continued growth. Consumers have demonstrated their preference for high quality sound by paying as much as $15 for a compact disc when the same material is available on vinyl album or cassette tape for as little as $7. As CD prices continue to fall, an increasing number of buyers are opting for its superior listening quality.

The increase in CD sales is the direct result of the tremendous acceptance of CD players in consumer homes. Compact Disc players now inhabit 19% of U.S. homes with penetration increasing on declining unit prices. The following chart displays the historical growth of compact disc players:

COMPACT DISC PLAYER SALES (ESTIMATED)
(In thousands)



Source: Consumer Electronics Report

One of the reasons cassette tapes have remained a popular medium is because it has the capability of being played and recorded on. Once the copyright problems surrounding the introduction of Digital Audio Tape (DAT) recorders have been solved, it is widely anticipated that cassette tapes will suffer the same destiny of vinyl records and be replaced by a digital device.

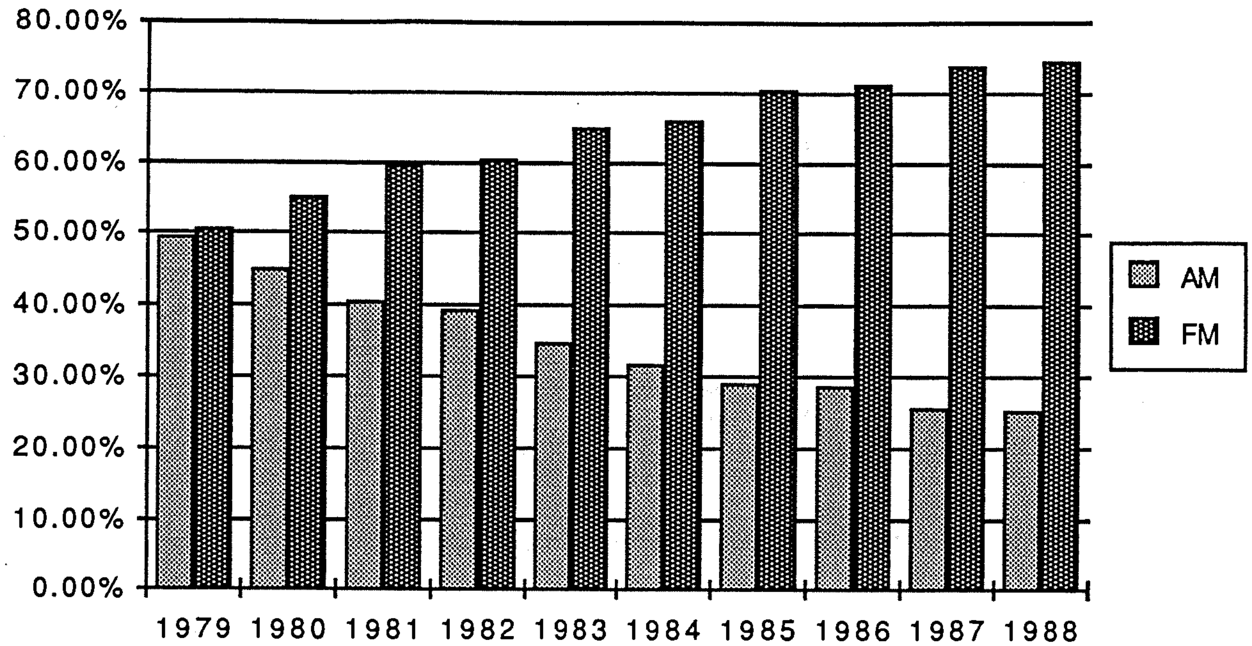
Listening audiences are demanding the same type of high quality sound from the radio broadcasting industry. However, due to the inherent limitations of existing radio transmitting means, broadcasters are ill-equipped to respond to the demand of their audiences. AM and FM bands are plagued with congestion and interference. Normal FM radio transmission is an analog process which is limited to 15 KHz audio bandwidth and subject to noise and distortion caused by atmospherics, signal processing and multipath reception effects. Good stereo reception is practically impossible in cars where reception suffers dramatically from multipath propagation.

The demand for and unavailability of CD quality radio has been recognized by the cable industry. Three companies are now offering digital radio systems which will provide cable customers with high quality, commercial-free music delivered to their home stereo systems. The service will cost between $8 and $10 per month. The companies involved are:

Company	***Service***
International Cablecasting	*CD/8*
General Instrument	*Digital Cable Radio*
Digital Radio Lab	*Digital Radio Channel*

According to a National Association of Broadcasters document, the companies expect to reach a 10% penetration of the 52 million cable households within the next 2 to 3 years. Research conducted by A.C. Nielsen suggests that about 14% of cable households surveyed are "very likely" to subscribe to the Digital Radio Channel service at $7.50 per month. Digital Radio Labs is affiliated with HBO and Viacom which indicative of broad support for the service. In addition to the monthly service fee, the DRC system costs about $2,000 to add a cable headend which the customer will have to purchase or lease.

The radio industry itself has established a precedent for the acceptance of advanced sound quality. With the introduction of FM radio, AM broadcasters have progressively attracted smaller audiences. The FM radio band is located in a higher frequency band than its AM counterpart and is therefore less susceptible to static, fading and background overlapping than AM transmissions. The following chart demonstrates the relative AM and FM audience shares over the past 16 years:



Source: R&R Magazine

It is therefore clear that listening audiences understand and respond to the quality of digital sound. When it first became available in the form of compact discs, they were prepared to purchase another component for their home stereo systems and pay roughly twice the price of vinyl records for the compact discs themselves. Focusing on radio, consumers are paying a service fee to cable operators for digital sound as an alternative to the free analog transmission provided by current broadcasting means. Radio broadcasters are thus finding it increasingly difficult to contest in today's competitive marketplace with yesterday's technology.

CD Radio, Inc. (CDR) can provide the bridge between the listening public's demand for greater sound quality and the radio broadcaster's inability to deliver it. A revolutionary technology has recently been developed which will allow radio listeners to receive compact disc quality sound at home and in their cars. The technology is called Digital Audio Broadcast and has been successfully demonstrated both in Europe and the United States. CDR is laying the foundation to bring DAB to commercial application.

THE MARKET

The CD Radio system essentially provides the radio broadcaster with two dramatically innovative features:

- o *the ability to broadcast radio programming with compact disc quality sound,*
- o *the ability to reach a national or international audiences with the superior signal.*

To the listener, the attraction of compact disc quality radio is obvious. It has already been demonstrated that consumers are willing to extend themselves for high quality sound and the CDR system is the next logical step in meeting their requirements. The attraction of a national radio broadcast may not be as obvious, but it is certainly one with precedent.

System Users

National television broadcasting is a time-honored enterprise in the United States. National networks have long dominated the delivery of television programs to the American public. Radio stations have been incapable of reaching national audiences because of technological limitations and consequently have had to forfeit significant revenues related to national ad campaigns.

By utilizing the CDR system, a radio broadcaster realizes economies of scale not available to the typical local station. In reaching a national audience, the system user will be able to spread programming costs over a significantly larger base which in turn will allow the broadcaster to increase its station's programming budget. The national broadcaster will be able to present such programs as concert appearances by famous rock musicians, sporting events such as the Super Bowl or World Series, and radio "name" personalities like Larry King which until now have been out of the reach of local station operators. In addition, with a national infrastructure, the broadcaster will be able bring immediate news, financial and political developments directly to its audiences. With this type of high profile programming, the radio broadcaster will be able to garner the same type national recognition as television studios through its own particular format.

The broadcaster will realize other significant operating efficiencies in addition to programming. The following schedule presents a comparison of typical operating results for radio stations operating in large and small markets, respectively:

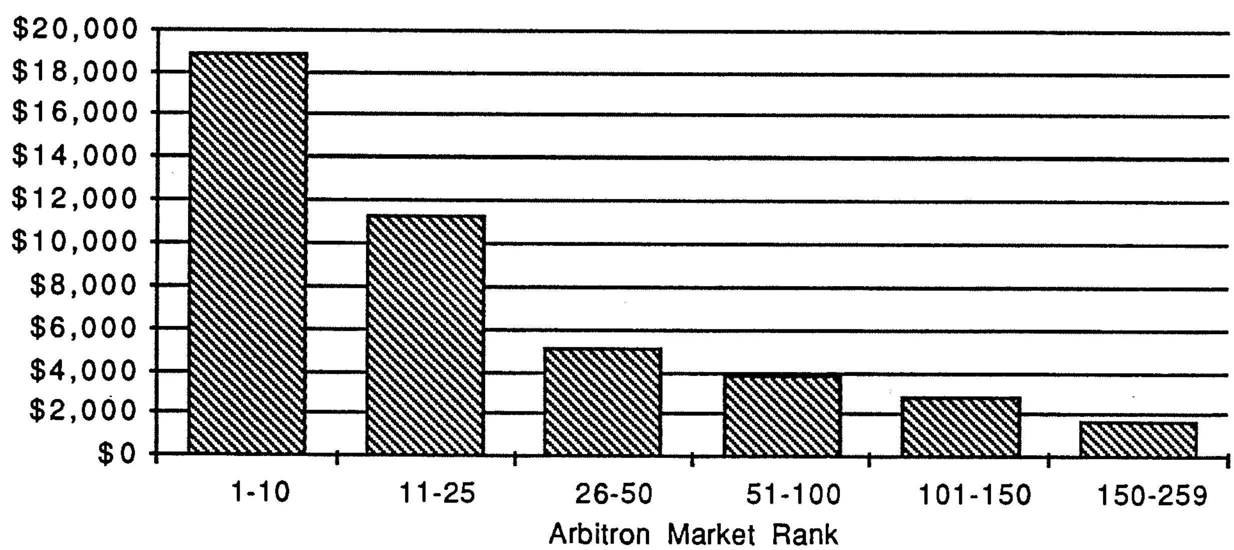
	Radio Station in Market with Population Over 2.5 Million *(in thousands)*	***Radio Station in Market with Population Between 500,000 and 1,000,000*** *(in thousands)*
Revenues:		
Network	225	23
National/Regional	2,667	485
Local	8,095	1,601
Total Time Sales	10,987	2,109
Net Revenues	9,406	1,841
Expenses:		
Technical	444	85
Programming/Production	1,747	342
News	460	65
Sales	1,373	398
Advertising/Promotion	1,076	186
General /Administrative	1,229	400
Total Operating Expenses	6,329	1,476
Operating Profit	3,077	365
Profit Margin	32.71%	19.83%

Source: Broadcast Investment Analysts, Inc.

Operating margins are highest in larger markets due to the fact that radio broadcasting is generally regarded as a fixed-cost enterprise with sales commissions normally being the only material variable cost. Because of the high ratio of fixed to variable cost, stations operating in the largest markets and generating the highest revenues will consequently experience the highest margins. This factor makes the CD Radio system a very attractive vehicle for potential broadcasters by covering national or international populations.

Acquisition prices of radio station are closely related to the size of the population they serve and the economic activity of the area. These factors determine the size of the potential listening audience and the advertising revenues that support the local station. Radio stations in larger markets are generally more profitable or have more upside potential than stations in smaller markets. Thus, prices paid for stations in larger markets are typically higher than those for comparable stations in smaller markets. The following chart illustrates average prices for stand-alone FM facility sales during the period from 1986-1987:

Average Sales Price for FM Radio Stations,1986-1987
(in thousands)



Source: Broadcast Investment Analysts, Inc.

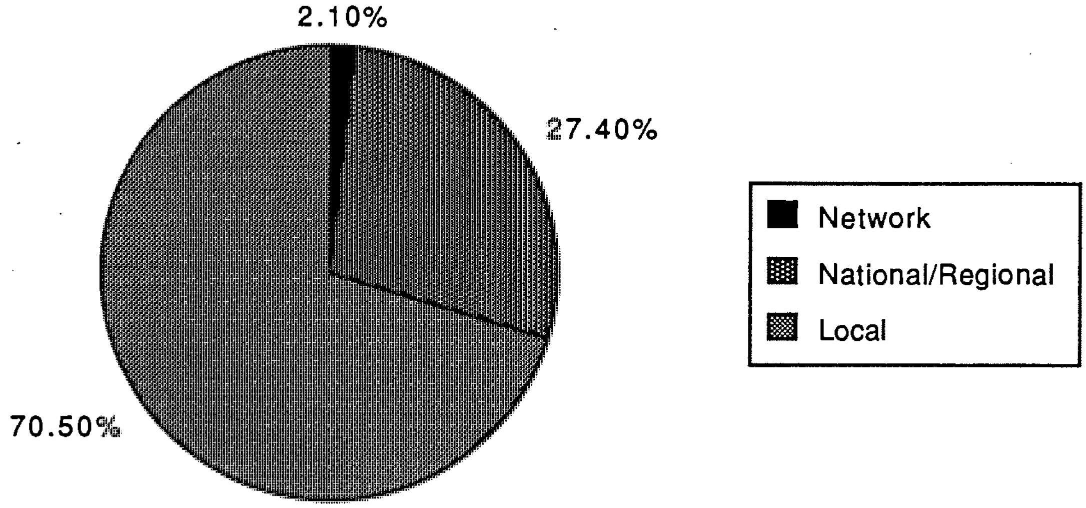
As the chart demonstrates, the value of radio stations is closely related to the size of the market in which it is located. As the CDR system has the capacity of delivering a national or international audience, only a little imagination is required to comprehend the resulting value to a well managed programming entity.

The potential users of the CDR system are numerous. First and foremost will be local stations seeking to become national "superstations". Television networks and cable companies with programming experience are also likely candidates. In essence, almost any media distribution company, including newspaper and magazine publishers could emerge as national broadcasters on a very profitable basis.

Advertisers

Commercial radio stations earn the majority of their revenues from the sale of airtime to advertisers. There are generally two classifications of advertising revenues: national and local. Historically, local advertising has comprised the majority of a stations overall revenues. The following diagram displays the various components of a typical radio station's advertising revenues operating in a large market:

Advertising Revenue Sources in Large Markets



Source: National Association of Broadcasters

Companies seeking to market products and services through mass communication mediums have concentrated on television as a means of reaching potential customers. Radio broadcasters have never gained the full attention of national advertisers primarily as a result of technological and logistical problems. Radio is unquestionably the most fragmented of all mediums in the broadcast industry. Today there are approximately 9,000 commercial radio stations operating throughout the country. Attempting to coordinate a national ad campaign among the vast number of stations has proven to be an overwhelming exercise.

In placing radio commercials on individual stations, national advertisers have normally utilized the services of large advertising agencies. The advertising firm will purchase "spot time" from the stations to air the commercials. It is the responsibility of the advertising firm to place the commercial on particular stations which will most effectively reach the client's target market. For this service, the firm will receive a commission from the radio station for selling the air time and also a fee from the advertiser for placing the ad which serves to significantly increase overall marketing costs.

Verifying performance of radio ads is cumbersome and uncertain at best. For the most part, verification is in the form of signed affidavits which creates a tremendous clerical burden in tracking paperwork. In addition, as the advertising firm is responsible for placing the ad on local stations across the country, effectiveness and therefore cost justification is difficult to determine.

A national broadcaster using the CDR system will solve a multitude of problems previously experienced by national radio advertisers:

- o by centralizing radio advertising with one national station, an advertiser will greatly reduce the logistical inefficiencies of verification,

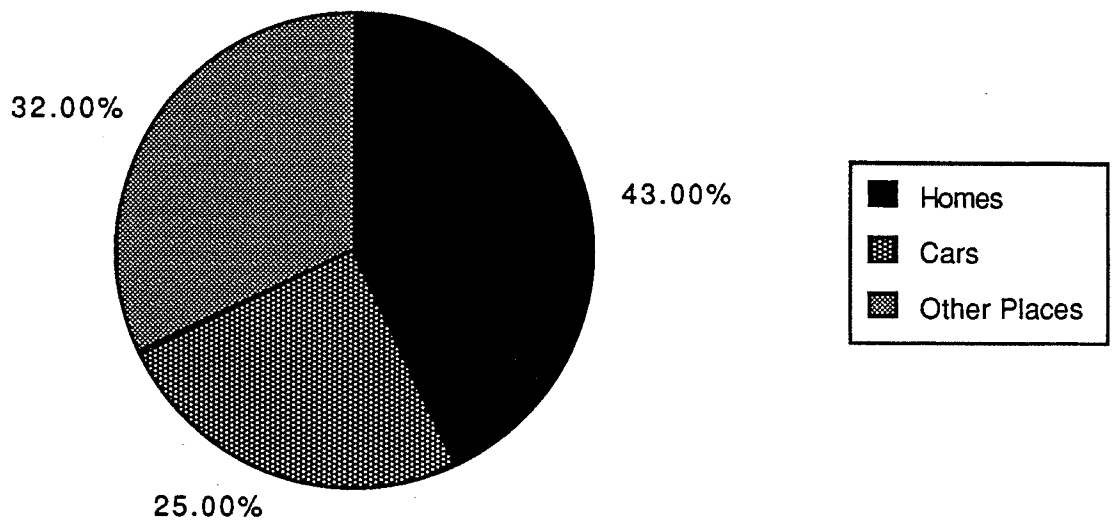
- o consumer response to radio advertising will be far easier to monitor by focusing on one station rather than numerous independent stations,

- o a national advertiser's in-house marketing staff will for the first time be able to contract with a single broadcaster for commercial time. As a result, significant efficiencies will be realized in eliminating the advertising firm's fees for placing radio ads thereby reducing overall marketing costs. Lower marketing costs will in turn attract additional advertisers serving to expand the national radio advertising revenue base.

A national radio broadcaster can provide an advertiser with an effective alternative to television. The comparable cost of television advertising greatly exceeds that of radio. With the technological and logistical drawbacks of national radio advertising being solved, companies are sure to rethink their commercial delivery strategies.

Radio advertising will offer marketing benefits which television cannot duplicated. Radio broadcasting delivers audiences largely unreachable by television such as individuals in cars and outside their homes. According to the National Association of Broadcasters, current FM audiences can be segregated as follows:

FM Audiences



As the diagram indicates, approximately 57% of FM audiences listen to radio away from home where the overwhelming majority of television viewing takes place. A broadcaster on the CDR system will provide the national advertiser with an effective means of reaching these audiences.

A company advertising on television can incur excess marketing costs as a result of most TV programming being directed towards the public at large, some of which may be out of the advertisers specific target market. Consequently, the advertiser is paying a premium to reach an unresponsive portion of the audience. With up to 100 channels of CDR system programming available in markets throughout the world, an advertiser will be able to identify effectively and economically the audience its wishes to reach through a process in radio broadcasting known as narrowcasting. In narrowcasting, programming is geared to the specific tastes of a homogeneous groups with similar interests. These groups can be identified in age, gender or ethnic segments. Examples of segments would be Hispanic communities, elderly, financial/business audiences, etc.. There are an average of six television stations per market operating throughout the country. For the most part, television stations offer little diversity in overall programming to viewers of various backgrounds because they must appeal to a much broader audience. With 100 channels of CD Radio available in every market, certain national broadcasters will have the flexibility to tailor their program material specifically to the preferences of their target audiences. Narrowcasting on a national basis could enable the broadcaster to reach massive audiences with high quality program material not available on a local level and also allow the advertiser to efficiently manage its marketing budget.

Quantitative Analysis

While national advertisers certainly have not fully utilized radio in their marketing strategies, they have not ignored it either. According to the Radio Advertising Bureau, national advertisers have spent well over a billion dollars in radio advertising in each of the past three years:

1989	$1,530,000,000
1988	$1,402,000,000
1987	$1,315,000,000

Multiplying the 1989 total by the average annual increase of approximately 8%, the current year national advertising total should be in the $1.65 billion range. Based on the revolutionary capabilities provided by the CD Radio system as discussed in this document, it is reasonable to conclude that future national radio advertising revenues will reach historic levels. The following schedule approximates future revenues for users of the CD Radio system: