advertising. Satellite Radio's impact would be indirect; that is, by reducing traditional radio's audience it would reduce local ratings and advertising revenue. Such reductions in audience and ratings would not translate into a one-for-one reduction in revenue, however, because the remaining local advertising media (local cable networks, newspapers, and other print media) are not perfect substitutes for traditional radio advertising. Therefore, the reduction in local ratings for traditional radio would exert some upward pressure on local advertising prices, partially offsetting the reduction in lost revenues due to lost audience.

Conclusion

Even using extremely conservative assumptions with regard to Satellite Radio's likely penetration (i.e., the comparability of pay and basic cable experience from 1975-1981), and as to Satellite Radio's ability to directly compete for traditional radio's advertising revenues, the estimated impact of Satellite Radio in the year 2004 is trivial. Finally, further reducing the significance of these estimates is the fact that Satellite Radio cannot begin service until 1998 and does not achieve the assumed 10% penetration until 2004—giving traditional radio ample to time to adjust to even these trivial impacts from Satellite Radio.

Appendix B: Sources

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Investing in Radio 1994, 3rd Edition, BIA Publishing. Small markets are defined as Arbitron radio markets rank 150-261.

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Mediamark Research Inc.

Car Radio Listenership
RADAR; Copyright Statistical Research Inc.; Wilkofsky Gruen Associates. Listeners are defined as 12 and older reached in the average quarter-hour in a 24-hour day.

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Appendix C: The Outlook For Radio Advertising by Dr. Arthur Gruen

Local radio advertising rose 9.2 percent in 1993, its biggest gain since 1985 and twice the increase of local broadcast television and local newspaper advertising. Radio's share of local measured media advertising has risen steadily over the last five years. As a relatively inexpensive medium for local advertisers, radio is at the leading edge of a resurgence in local advertising. In addition, as a mobile medium, a radio ad is often the last commercial a consumer hears before making a purchase. In recent years, local advertising has been adversely affected by the recession and by restructuring among retailers and local advertisers. The virtual completion of retailer restricting and the improvement in the economy contributed to the large increase in local radio advertising in 1993 which has continued in 1994.

With restructuring at an end and with the economy expanding at a faster rate, local radio advertising should remain strong. We expect local radio advertising to continue to grow faster than local television or local newspaper advertising. Radio is accessible to more advertisers because of its lower unit costs; radio provides a more targeted advertising environment than either newspapers or television; radio reaches 95 percent of adults each week; and radio is the only electronic medium that travels with its audience. For these reasons, radio will continue to be appealing to local advertisers—in both large and small markets across the U.S. Consequently, we have revised our forecasts upward. Based on our long-standing forecasting experience, we conclude that radio has emerged into a new phase characteristic of mature industries where it will garner increasing shares of overall media advertising independent of short-run cyclical developments.

Moreover, the new technologies and the new regulatory environment should prove especially beneficial to radio. Because of the proliferation of satellite services, radio stations have access to a wider variety of programming alternatives. At the same time, the new media stimulate interest in special topics, interests which are often served by local and national talk radio and other specialized formats. Radio has proven to be particularly resilient in adapting to new technologies, and over the last decade, while the television and print industries have been buffeted by technology, radio has thrived. In addition, the relaxation of the duopoly rules has given radio operators greater latitude in improving their efficiency, productivity, and earnings.

Biography of Dr. Arthur Gruen

Arthur Gruen is an economist with more than 15 years experience focusing on the leisure, entertainment, media and communications industries. A co-founder of Wilkofsky Gruen Associates, he is a specialist in forecasts of entertainment media markets using statistical simulation and econometric techniques. He is the author of the widely acclaimed Veronis, Suhler & Associates Communications Industry Forecasts. He has also developed pricing and other strategies related to media businesses based on mathematically specified demand and supply equations. He advises senior management on media trends and comparative media prospects, and specializes in developing strategies to address challenges and opportunities. His clients include investment banks, and media companies. He has also served as an expert witness in a number of litigation proceedings.

Dr. Gruen was Director of Industry Studies at CBS from 1981-1985. He earned his Ph.D. and M.A. in economics from Tufts University and has a B.A. in economics from the University of Pennsylvania.

Appendix D: About the Authors

This report was prepared by **InContext®** Inc., an information company based at 1615 L Street, Suite 650, Washington, D.C. 20036 (phone 202-659-1023, fax 202-659-1109). InContext specializes in politico-economic analyses that take economic data (such as price changes of local goods and services) or socio-economic data and juxtapose those data with local geographic areas defined either by political jurisdiction (such as a state assembly district or city council district) or an economic service jurisdiction (such as a cable television franchise area, a telephone company service area, a daily newspaper service area, a local gas utility service area, a television market area, or a Yellow Pages market area).

InContext's analyses are distinguished by extensive and creative uses of digital computer software for multicolor mapping and charting. InContext's politico-economic analyses rely on the age-old adage that a picture is worth a thousand words.

William Lilley III, chairman and cofounder of InContext, Inc., is an economic historian with broad experience in the private and public sectors. Lilley was a senior corporate official of CBS Inc. in New York. Previously, he served as director of the U.S. Council on Wage and Price Stability and as staff director of the Budget Committee for the U.S. House of Representatives. He received his Ph.D. from Yale University, taught at Yale, and has written widely on economic policy and the communications media.

While at CBS, Lilley served from 1980 to 1982 as a member of the Board of Directors of the National Association of Broadcasters and as chairman of the NAB's Committee on Science and Technology. His committee authored in 1981 the NAB's in-depth study of *New Technologies Affecting Radio and Television Broadcasting.*

Laurence J. DeFranco, president and cofounder of InContext, Inc., has been providing information to public and private sector leaders for over thirteen years. DeFranco has coauthored several studies on the effects of economic policy on businesses. He has provided expert testimony and addressed industry leaders on telecommunications and advertising issues. He is also president of Program Flow, Inc., a research and consulting firm in McLean, Virginia. Previously he worked for CBS Inc.

Lilley and DeFranco recently authored *The Almanac of State Legislatures* (Congressional Quarterly Books; Washington, D.C., 1994). In preparing this report, Lilley and DeFranco utilized the analytical skills of Arthur Gruen, a principal in and co-founder of the media forecasting firm of Wilkofsky-Gruen Associates, to review their findings. See attached affidavit by Arthur Gruen.

APPENDIX B

Satellite Radio CD Music Bandwidth Requirements

Satellite Radio CD Music Bandwidth Requirements

INTRODUCTION

This paper technically analyzes the radio frequency bandwidth that is required for digitally transmitting CD quality stereo music from geosynchronous satellites to mobile and fixed users in the United States using the FCC allocated 2310-2360 MHz band. Due to numerous technical and service considerations described subsequently, the analysis addresses a range of required bandwidths.

The paper is organized so that the underlying technical principles are defined first. This is followed by an analysis of the range of radio frequency bandwidths required for a single CD stereo music channel transmission, then by an analysis of the bandwidths required for multiple CD stereo music channel transmission and lastly by making bandwidth comparisons with other CD music transmission systems.

PRINCIPLES

It is most important to understand technically the Satellite Radio service. Due to the necessity to serve mobile vehicles whose orientation with respect to a geosynchronous satellite changes in time with vehicle movement, the vehicle antennas must have low directivity (i.e., omnidirectional in azimuth and limited gain in elevation), since high directivity vehicle antennas would necessitate tracking the satellite either by mechanically moving the antenna or by electronically steering the directive beam. Such tracking antennas are not feasible due to their size, configuration and cost. The low directivity antennas employed by Satellite Radio systems are small, inexpensive and aesthetically acceptable but create the requirement for high satellite effective

isotropic radiated power (EIRP). This results in very expensive satellites and launch vehicles with a typical system requiring $400 million investment but permits the use of affordable consumer automobile and home receivers.

It is evident from the previous discussion that the foremost concern is to maximize the capability of the satellite to provide Satellite Radio by minimizing the amount of satellite EIRP required to provide a CD stereo music program channel. This impacts the desired radio frequency transmission bandwidth, as described in the following sections of this paper, and generally results in different bandwidth requirements than used in terrestrial transmission systems where high EIRP's can be generated with relatively low cost.

The minimization of required satellite EIRP to provide a CD stereo music channel has importance beyond the system economics. The minimization also reduces the satellite's radiated power flux density incident on countries adjacent to the United States thereby facilitating interservice frequency sharing and interference coordination. The total minimum satellite EIRP is the product of the EIRP per CD stereo music channel times the number of channels provided, assuming enough radio frequency bandwidth is available and efficient channel multiplexing is employed. A commercial geosynchronous satellite for Satellite Radio is normally designed for a standard bus whose configuration yields a maximum total satellite EIRP over a defined geographical service area. The lower the satellite EIRP per CD stereo music channel, the more channels can be accommodated if sufficient radio frequency bandwidth is available. It is noted that significant changes in satellite EIRP can cause dramatic changes in space segment costs, such as when the power capacity of a particular satellite bus is exceeded and a larger satellite bus and more powerful launch vehicle are then required [1].

A Satellite Radio transmission can be analytically divided into the required information rate, its corresponding transmission rate and the resultant transmission bandwidth which is also a function of the multiplexing and modulation techniques employed. The following discussion will first characterize the required radio frequency bandwidth for a single CD stereo music transmission in a Satellite Radio Service so that multiplexing need not be considered, and then addresses multiplexing techniques and their consequent bandwidth requirements.

INFORMATION RATE

In all known terrestrial and satellite systems used for digital transmission of CD stereo music, compression of the music at its source is performed to reduce the information rate needed to be sent. This also proportionately reduces the required satellite transmitted power (i.e., satellite EIRP) and the required transmitted radio frequency bandwidth for equivalent system and performance characteristics. The compression may be generally compared with that employed by satellite direct broadcast television but, for Satellite Radio, the music is processed by algorithms which remove redundant and unnecessary information and information which would not be heard due to the dynamic auditory characteristics of the human ear [2].

Several digital music compression subsystems have been built, including those by AT&T, Sony, Dolby, Scientific Atlanta, and others. The two most applicable currently to Satellite Radio and to terrestrial digital audio broadcasting (DAB) in the United States are the perceptual audio coding (PAC) subsystem developed by AT&T Bell Laboratories [3] and the MUSICAM subsystem originally developed by the European Union in its EUREKA-147 program [4]. These two subsystems are believed particularly applicable, because they have both been thoroughly tested in the Electronic Industries Association (EIA) - National Association of Broadcasters (NAB) competitive DAB

evaluation program at the National Aeronautics and Space Administration (NASA) laboratories in Cleveland, OH (Lewis Research Center). The laboratory testing is complete on two proposed terrestrial DAB systems and on one Satellite Radio system using PAC and on three other terrestrial DAB systems using MUSICAM. CD stereo music quality in the year and a half long test period was evaluated subjectively in the unique audio performance evaluation facilities of the Canadian Research Council (CRC) in Ottawa, Canada. All of the test data have been made available to the FCC and other interested organizations last month.

There are two different techniques commonly used for CD stereo music compression. One is where each of the two channels in a stereo pair is individually compressed and then multiplexed together, and the other is where both channels are simultaneously processed (i.e., joint encoding). Extensive testing has been performed on PAC joint encoding of CD stereo music which achieves a compressed information rate of 128 kb/s. PAC operating at both a 128 kb/s and a 160 kb/s information rate was extensively tested in the EIA/NAB evaluation program, including demonstration of the 160 kb/s information rate through a S-band frequency NASA satellite (i.e., the Tracking and Data Relay Satellite-TDRS). MUSICAM achieves similar performance for individual encoding with a compressed information rate of 256 kb/s. It appears that 128 kb/s to 256 kb/s is the applicable required information rate range for Satellite Radio to achieve high quality CD stereo music transmission.

Three technical matters are noted:

1) The decoders of the compressed digital music to achieve high quality stereo CD require an input information bit error rate (BER) of 10^{-5} or less.

2) The quality of reception in an automobile may be limited by the audio speakers and their position as well as by road noise.

3) The information rates often quoted by terrestrial DAB systems may be higher since they include, besides the CD stereo music, data transmission services.

TRANSMISSION RATE

The discussion in the section preceding on PRINCIPLES addressed the need in Satellite Radio systems to minimize the required satellite EIRP due to technical, service capacity and economic constraints. In all modern digital satellite transmission systems, part of the minimization is accomplished by convolutionally encoding the information and Viterbi decoding the received transmission [5]. Although there are numerous similar techniques (e.g., trellis encoding), the basic principle is to encode the signal so it is as distinct as possible from noise. This allows at the receiver the decoder to estimate what the original transmitted information had been when occasional errors in the data transmission are caused by the noise and to correct such errors. This type of encoding/decoding is one form of forward error correction (FEC). The amount of transmission performance improvement by use of convolutional encoding is related to how many encoding bits are added to the information bits.

Most satellite digital transmission systems use convolutional encoding rates of 1/2, 1/3 or 1/4 with a constraint length (k) equal 7. Such coding rates respectively double, triple or quadruple the information rate but reduce the required satellite EIRP for a bit error rate of 10^{-5} by 5.2 dB, 5.5 dB and 5.9 dB respectively over a non-encoded transmission. This reduces the required satellite EIRP per CD stereo music channel by over 300% at the expense of bandwidth and some complexity for the decoder in the user receivers. It is noted that the decoder is assumed to use "soft decision" (e.g., 4 bit words), coherent demodulation and operate in a gaussian noise distributed transmission channel. The satellite transmission channel in a mobile environment is not gaussian under all conditions but, with reasonable data time interleaving, can

approximate this noise distribution, particularly in rural areas. If the mobile transmission channel is modeled in a Rayleigh fading environment typical of urban areas, the amount of FEC performance improvement decreases by 1.2 to 2.5 dB with respect to the previous gaussian case. For the Rayleigh environment, the use of 1/4 rate convolutional coding can have a 160% transmission performance advantage over 1/2 rate [6] making it very desirable. Also, due to its spreading effect, added mitigation against frequency selective fading is attained.

Further FEC encoding of the digital information to be transmitted is generally performed to obtain even greater reduction of required satellite EIRP. The information digital data stream is divided into blocks of data, and each block encoded by a FEC block code. The preferred block code is currently "Reed-Solomon" (RS). The dual or concatenated coding of the information is described as the "inner code" for the convolutional FEC and the "outer code" for the RS block FEC. Devoting approximately 12% for extra bits to achieve a RS block code, a further reduction of required satellite EIRP of 25% is achieved. For example, if a block of 140 bytes is RS encoded to 160 bytes at the transmitter, the RS decoder in the receiver can correct 10 incorrect bytes, again assuming an average transmission error rate of 10^{-5}. The RS decoder in the user receiver also normally is used to notify the information signal decompressor and/or to squelch the audio output when more than 10 incorrect bytes are detected in the block. The use of the block FEC code in conjunction with the convolutional code is particularly effective, since the RS FEC code operates against a different error distribution than the convolutional code (i.e., the FEC block code is linear since each block is independently decoded) [7].

MODULATION

The information rate was converted to a transmission rate in the last section of this paper and now must be modulated on a radio frequency carrier for transmission by the uplink earth station to a geosynchronous satellite where the uplink radio frequency carrier is translated to the downlink radio frequency, amplified in power and retransmitted to the desired coverage (i.e., service) area on the earth. The requirements for modulation are:

1. Satellite Power Amplifier Efficiency. It is required for minimum satellite EIRP per CD stereo music program to operate the satellite final power amplifier (i.e., transmitter) at maximum efficiency (i.e., saturated output). This precludes modulations which need linear power amplifier operation (so high intermodulation and distortion products are not generated), such as amplitude modulation. An increase in required satellite EIRP per CD stereo music program of over 250% would be required if linear operation were used [8]. A class of modulations suitable for efficient operation at final power amplifier saturation is called constant envelope.

2. Coherent Detection. The user receivers of the satellite transmission will require less satellite EIRP per CD stereo music channel if they use coherent detection rather than noncoherent detection. Coherent detection requires a modulation where the demodulator can detect the phase of the carrier within the received signal. Simplistically, this allows the receiver to filter out the quadrature noise component as contrast to noncoherent detection where both the quadrature and in-phase noise components effect the signal.

A modulation which achieves the foregoing and, consequently, is widely used in satellite digital transmissions is phase-shift keying (PSK). The simplest form of PSK

modulation is binary (BPSK). By operating two BPSK modulators in quadrature and summing their outputs, quaternary phase-shift keying (QPSK) modulation is achieved with the same transmission rate and error rate as BPSK using half the required radio frequency bandwidth. Since spectrum conservation is vital, QPSK is the preferred modulation. Variations of this modulation, such as offset QPSK (OQPSK) can be used to shape the spectral sidelobes, thereby minimizing adjacent and out-of-band interference [9].

The theoretical performance of QPSK with coherent detection is:

$$BER = 1/2\ cef \sqrt{\frac{Eb}{No}}$$

where BER is the bit error rate probability, Eb/No is the bit energy to noise density ratio and cef is the complementary error function. This equation gives a theoretical 10^{-5} <u>unencoded</u> bit error rate at an Eb/No of 9.3 dB, but practical systems perform approximately a decibel worse. The required radio frequency bandwidth for a practical QPSK transmission taking into account spectral growth in a saturated amplifier and practical filtering is 1.15 to 1.25 times the transmission bit rate. A factor of 1.2 will be used in all subsequent QPSK bandwidth requirement calculations herein.

There are forms of modulation involving higher number of phases than 4 and multiple amplitude levels which can utilize less bandwidth than QPSK for the same transmission rate. Since these require satellite output power linearity and much higher Eb/No for detection, such complex modulations are not used in satellite transmission systems because correspondingly higher satellite EIRPs would be required. A good illustration of this is mentioned by the Commission in Paragraph 31 of the NPRM where it is noted that the ATV Grand Alliance system could "deliver 75 CD quality stereo channels in 6 MHz as a terrestrial service". This statement simply means that the ATV digital television transmission of approximately 18 Mb/s in the 6 MHz bandwidth could

be utilized for quality audio services to the home instead of video service. Terrestrial systems of this type use such modulations as 16 QAM (Quadrature Amplitude Modulation) or 4 VSB (Vestigial Sideband). The television transmitters are high power and generally operate in a linear mode for providing service within a typically 25 mile radius. This contrast to the satellites which provide Satellite Radio over a 23,000 miles distance with modest transmitter powers. Quantitatively, 16 QAM would require over 300% more satellite power than QPSK for linear transmitters and would increase the total required satellite power by over 800% [10].

SINGLE CHANNEL TRANSMISSION BANDWIDTH

The previous discussion allows calculation of the radio frequency bandwidth for the most efficient transmission (i.e., minimum satellite EIRP for a single CD stereo music program) under the assumptions and principles previously defined.

Compressed minimum information rate:	128.0 kb/s
Block FEC (RS of 12%):	143.4 kb/s
Convolutional FEC (1/4 rate):	573.6 kb/s (transmission rate)
QPSK Modulation (symbol rate)	286.8 ks/s
Transmission Bandwidth (1.2)	344 kHz

MULTIPLEXING

The previous discussion dealt with a single CD quality stereo music channel transmission. The requirement for a Satellite Radio service is to transmit multiple channels which is accomplished by combining or multiplexing the individual channels. The basic multiplexing techniques are time division (TDM), code division (CDM) and frequency division (FDM).

TDM

TDM is an efficient multiplexing method from a bandwidth minimization viewpoint. Assuming a small bandwidth increase for synchronization, demultiplexing data and service channels, the minimum multiplexed bandwidth is approximately the product of the number of channels times the required individual channel bandwidth. For mobile reception service using TDM, multipath resistance may be provided by additional satellite EIRP, diversity or combinations thereof.

CDM

Code division multiplexing requires more satellite EIRP, since the satellite transmitter cannot be operated at saturation for reasons previously described. However, CDM can be multipath and interference resistant with the degree of resistance dependent on the spreading ratio (the spreading code rate or "chip" rate divided by the transmission rate) [11]. The spreading ratio is also called the processing gain for direct sequence spread spectrum modulation. The system design for CDM generally requires a large spreading ratio both to maximize the resistance to multipath and interference and to have a code length that allows many orthogonal code sets to be derived.

Satellite Radio systems using CDM are generally designed with a minimum spreading ratio in the range 32-64 (15-18 dB processing gain). Using 18 dB processing gain, 160 kb/s information compression, half rate convolutional and 12% RS FEC encoding, the minimum required transmission radio frequency CDM bandwidth is 11.5 MHz which, with guardbands, would require approximately 13 MHz bandwidth. The spreading code(s) are pseudorandom and orthogonal to each other, so the multiplexed channels do not interfere with each other. Orthogonal codes for this purpose which, after demodulation, yield minimum code noise are a class called "balanced Gold codes." It has been shown that there are $2^{k-1}+1$ such codes where k

equals the shift register length. For the above CD stereo music channel transmission system and a 12.5 MHz radio frequency bandwidth channel, thirty-three channels could be multiplexed. Only seventeen channels could be multiplexed in a 6.25 MHz bandwidth.

It is also possible to use "synchronized CDMA" with orthogonal Hadamard-Walsh codes and, as shown by Viterbi [12], the number of multiplexed channels C

$$C \leq (W/R)\, r$$

where W is the transmission bandwidth in Hertz, R is the data rate in b/s and r is the FEC code rate. Similar numbers of multiplexed channels to the previous example result.

FDM

Frequency division multiplexing can take several different forms. Three forms are:

1. Subcarrier Selective Combining. Essentially each CD stereo music program channel is modulated onto a different radio frequency subcarrier and the subcarriers after filtering are combined. This method is not proposed for Satellite Radio since it is inferior to the following methods with respect to multipath mitigation and frequency selective fading.

2. Coded Orthogonal Subchannels. Coded orthogonal frequency division multiplexing (COFDM) is being implemented on a demonstrational/developmental basis for terrestrial DAB in Europe and Canada as mentioned previously in the Section dealing with Information Rate. Several variants of the multiplex exist but, in a generalized description, it provides 6 CD quality stereo music programs in a 1.5 MHz radio frequency bandwidth (i.e., each CD stereo music program occupies 250 kHz bandwidth). This is accomplished by compressing each CD stereo music channel to a

256 kb/s information rate, scrambling each for energy dispersal, FEC convolutionally encoding each at half rate, time interleaving and digitally combining them. This combined digital transmission is then divided among 384 individual orthogonal carriers (i.e., subchannels). The subchannels are equispaced at 4 kHz across the 1.5 MHz bandwidth with each carrier modulated by a subset of the data stream so that a 4 kb/s data throughput results. No implementation plan to use COFDM for Satellite Radio exists but studies of such future possibilities have been done by Canada [13] and by the European Space Agency [14]. These studies have recognized that COFDM transmission through a satellite will require that the satellite's final power amplifier be operated below saturation, thereby requiring over 100% increase in the satellite's required EIRP per CD stereo music channel.

3. In-Band-On-Channel. Another form of FDM uses one terrestrial DAB channel multiplexed on an existing analog FM transmission. Three FM IBOC systems have completed laboratory testing under the previously described EIA/NAB test program. The USA Digital Radio FM IBOC will be described herein only because it has been publicly demonstrated (e.g., Las Vegas in April 1995). In this technique, the CD stereo music compression and FEC rates are both variable so that, in addition to the music, ancillary digital data of up to 64 kb/s can be transmitted. The composite transmission rate is 384 kb/s. The 384 kb/s is divided among 48 subchannels each impressed with a subset of the data at an 8 kb/s rate by biphase keying. The total spectrum occupied by the transmission is 460 kHz [15].

4. Separate Carriers. It is possible to send each CD music program on its own separate radio frequency carrier which is often called a single channel per carrier (SCPC) system. This would not be effective for Satellite Radio systems, since the satellite's final power amplifier must be operated linearly so low intermodulation products result. The requirement for satellite power amplifier linearity would cause

satellite EIRP per CD stereo music program to be a few times higher than other previously described multiplexing methods. An alternative to this method is where several CD stereo music channels are combined, for example using a time division multiplex, and transmitted at one radio frequency. Several other CD stereo music channels are similarly combined and transmitted at a second frequency. The same can be done for additional frequencies. Assuming appropriate system design, the satellite then contains multiple output power transmitters at the various frequencies each of which can operate at saturation. This allows a satellite design with lower power, multiple output power efficiently operating transmitters but at the expense of transmitter combining filters. Assuming the separate frequencies are close to each other for spectrum efficiency, the required low loss combining filters on the satellite at S-band are a difficult design problem. In any case, no transmission spectrum savings result from this form of FDM as contrast to TDM or CDM.

SERVICE QUALITY

Satellite Radio service requires high quality and availability to mobile and fixed users. Discussion of only mobile user requirements (e.g., automobiles) is contained herein since high service quality is much more difficult to achieve for mobile service than for fixed users.

The mobile user receiver in Satellite Radio service requires a small size receiving antenna which provides omnidirectional coverage in azimuth angle (i.e., 360°) and limited coverage in elevation angle (i.e., 20°-60°) [16]. Assuming this is done perfectly and the automobile is operating on a smooth earth, it is only necessary that the satellite provide enough EIRP so that the received power exceeds the receiver's thermal noise threshold operating value by a fixed amount which, as earlier discussed, would create an Eb/No to achieve 10^{-5} BER. S-band propagation does not

suffer from appreciable rain loss or other transmission effects, although margin must be allowed for receiving system manufacturing variances, other small changes in the total transmission system and effects from subsystem aging. Returning to the real world, the Satellite Radio service essentially requires "line-of-sight" transmission between the user vehicles and the geosynchronous satellite, and there will be signal outages whenever major obstructions block the line-of-sight (e.g., buildings, hills, overpasses, etc.) or partially obstruct it (e.g., tree branches and foliage). Additionally, multipath fading of a diffuse nature (e.g., scattering), specular nature (e.g., reflections from buildings or trucks) and frequency selective nature must be overcome by a combination of additional satellite transmitted power and/or diversity.

A method of mitigating outages from blockage over wide coverage areas in a Satellite Radio service is by diversity. Diversity also mitigates multipath. There are various types of transmission diversity, such as spatial, frequency, time and polarization. Each has different mitigating characteristics. For instance, dual satellite spatial diversity provides two independent transmission paths with differing angles of arrival in azimuth and elevation, whereas frequency diversity virtually eliminates frequency selective multipath fading. Therefore, service quality can be maximized by designing Satellite Radio systems which incorporate a few types of diversity. Additionally, besides higher receiving signal to noise power margins, other methods of mitigation, such as high satellite elevation angles and multipath resistant modulations can be employed [17] to improve Satellite Radio service quality.

CONCLUSION

The previous analysis describes the numerous technical considerations and varying characteristics which determine the required radio frequency transmission bandwidth for a Satellite Radio service both on a per CD stereo music channel basis

and on a multiplexed multi-channel basis. Radio frequency spectrum must be conserved so it is vital to use the minimum radio frequency bandwidth required to provide the service both efficiently and economically.

The largest contributing factors determining radio frequency transmission bandwidth per CD stereo music channel are the information compression and the FEC convolutional coding rates. Using the previously described Satellite Radio system principles and assumptions, the minimum satellite EIRP per CD stereo music channel requires a radio frequency transmission bandwidth of 344 kHz.

An efficient design of a Satellite Radio system maximizes the number of CD stereo music program channels provided within the total satellite EIRP available due to the high space segment costs, which require hundreds of millions of dollars investment. However, the maximization of the number of channels must take into account the necessary high service quality since users may be required both to pay subscription charges and to purchase new radios. Service quality mainly manifests itself in the music program fidelity (i.e., the compression information rate chosen) and in the amount of outage from blockage and multipath (i.e., received power margin or diversity methods employed). Consequently, many technical, service quality and business choices confront the designer of a Satellite Radio system, and selection of the choices should not be unduly constrained if innovative and competitive Satellite Radio services are to be offered to the United States public in an effective and economical manner.

The four Satellite Radio applicants have agreed to divide equally the total 2310-2360 MHz radio frequency band. Each applicant could provide approximately 35 stereo CD music channels in the resulting 12.5 MHz radio frequency bandwidth, including provision of a service channel and two telemetry channels. The 12.5 MHz bandwidth would also allow applicants to employ CDM as previously described, which

provides advantages with regard to multipath and interference mitigation. The 344 kHz transmission bandwidth per CD stereo music channel was calculated on a compressed information rate of 128 kb/s with 1/4 rate convolutional FEC coding and QPSK. A 344 kHz bandwidth transmission channel would alternatively allow approximately 35 stereo CD music channels if an information rate of 160 kb/s with 1/3 rate FEC coding were employed or if an information rate of 256 kb/s with 1/2 rate FEC coding were employed, so that selection of different technical choices by various applicants is still possible thereby providing the flexibility of implementation so necessary in the provision of a new service to the public.

9/13/95

LIST OF ABBREVIATIONS

BER	Bit Error Rate
BL	Bandwidth Limited
BPSK	Binary Phase-Shift Keying
CDM	Code Division Multiplex
CDMA	Code Division Multiple Access
COFDM	Coded Orthogonal Frequency Division Multiplexing
CRC	Canadian Research Council
DAB	Digital Audio Broadcasting
EIA	Electronic Industries Association
EIRP	Effective Isotropic Radiated Power
FCC	Federal Communications Commission
FDM	Frequency Division Multiplexing
FEC	Forward Error Correction
IBOC	In Band On Channel
NAB	National Association of Broadcasters
NASA	National Aeronautics and Space Administration
NRE	Non-Recurring Engineering
OQPSK	Offset Quadrature Phase-Shift Keying
PAC	Perceptual Audio Coding
PL	Power Limited
PSK	Phase-Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
RS	Reed Solomon
SCPC	Single Channel Per Carrier
TDM	Time Division Multiplexing
TDRS	Tracking and Data Relay Satellite
TT&C	Tracking, Telemetry and Command
VSB	Vestigial Sideband

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