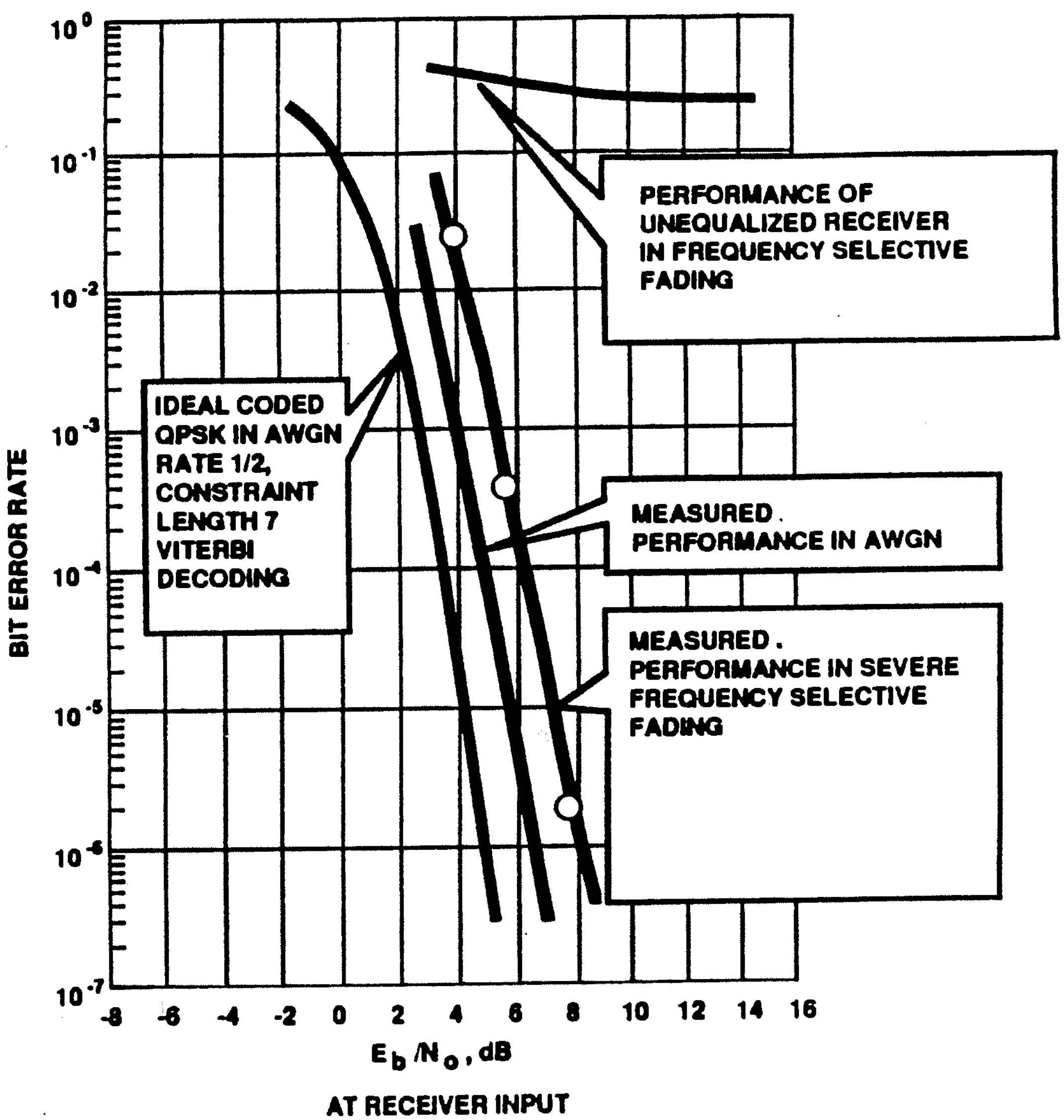
Figure 2: Performance in severe frequency-selective fading environment.



5.2 RECEIVING ANTENNAS. A variety of receiving antennas will be used in the CD Radio, Inc. system. All of the antennas will be circularly polarized. For fixed installations, such as homes and office buildings, a multi-turn helical antenna exhibiting a gain of about 10 to 12 dBic would be mounted outside or in the attic, and, depending on the relative signal level in the service area, pointed either towards the satellite or towards the terrestrial transmitter.

Portable receivers would use either a single element or a collinear array of circularly polarized, crossed drooping dipoles with half-wavelength elements. These elements exhibit a gain of about 5 dBic. Alternatively, a planar, circularly polarized micro-strip patch antenna, which also exhibits a gain of about 5 dBic and is a half-wavelength on a side, could be used. The physical dimensions of these antennas are on the order of 10 cm for an operating frequency of 1500 MHz.

Vehicular antennas will comprise four, collinear crossed drooping dipole elements to provide for quad-spatial diversity. These elements must be separated by at least one-half wavelength to ensure that the signals received by each element will fade independently. Based on the separation requirement, the height of the array will be on the order of two wavelengths, or 40 cm.

The receiver low-noise amplifier is a High Electron Mobility Transistor (HEMT) device exhibiting an operating noise temperature of 100 K. The antenna noise temperature, for crossed drooping antennas, is expected to be on the order of 50 K based on measurements performed in rural and suburban areas [9].

6. Radio Frequency Plan & Polarization.

6.1 GENERAL. Frequencies in the range 1470-1530 MHz will be used for satellite transmissions. This band of 60 MHz can provide 200 channels of 300 kHz each. About one-third of the band, or 19.8 MHz, which can provide 66 channels of 300 kHz each, will be designated for use in each of the regional beams.

By using contiguous blocks of frequencies for each beam, frequency re-use by neighboring countries is facilitated. Moreover, as satellite antenna technology is improved in future years, to permit even smaller beams at these L-band frequencies, the three regions of the United States can be subdivided (as in a terrestrial cellular system) and the blocks re-used within regions.

Circular polarization will be used on the downlinks.

6.2 TERRESTRIAL REPEATERS. Terrestrial repeaters will be provided as an integral part of the CD Radio system. The use of repeaters ensures the availability of uncompromised, CD-quality stereo broadcasting service in heavily shadowed urban areas that would otherwise receive weak signals.

The CD Radio frequency plan is based on a reuse factor of 3. Thus, each of the satellite beams is assigned 1/3 of the total available satellite spectrum. Within each of the satellite beam areas, the remaining frequencies are available for use by the terrestrial repeaters (except in areas where the satellite beams overlap one another). In the overlap areas, only one set of the frequencies is available on a non-interfering basis. As an example, consider three blocks of frequencies. One-third of the frequencies will be assigned to each block, F1, F2, and F3. Each of the 66 program channels will be associated with a specific 300 kHz bandwidth channel in each frequency block. In each region of the country, one of the blocks will be used for the satellite transmissions and the other blocks will be used for terrestrial transmitters.

Frequencies for terrestrial transmitters must be chosen so that there is no interference from the same frequency used for a satellite channel in the adjacent beam.

In other words, if frequency block F2 is used in the Central beam, channels from block F1 could be used for terrestrial transmitters in that same Region, except in its western parts where satellite signals from the Western Beam (which also uses Block 1) can be received. Similarly, channels from Block 3 could be used for terrestrial transmitters in the Central Region, except in its Eastern portions, where signals from the Eastern Beam (which also uses Block 3) can be received.

The radiated power of the repeater will be on the order of 30 dBW to 40 dBW per stereophonic channel. The repeater site will be selected to permit the transmitting antenna to be mounted sufficiently high to provide the desired coverage. The antenna will generally be circularly polarized and have an omnidirectional pattern with 5 dBic gain. This will provide service to a vehicular receiver at distances on the order of 20 km.

The modulation format and audio coding of the signal transmitted by the repeater will be identical to that used on the satellite broadcasting channel.

The consumer receivers incorporate circuitry to sample the signals received on the selected channel in blocks 1, 2, and 3 and after a sufficient number of samples, to switch to the block which has the strongest signal.

6.3 FEEDER LINKS. Feeder links will operate in the L-band now allocated to the FSS (Earth-to-space), that is, in the range 27.5-29.5 GHz. Satellites will utilize "bent-pipe" transponders, that is those employing simple frequency-translation. Thus, the same bandwidth will be required for feeder links, 60 MHz.

Each of the satellites will use a single, high-gain receiving antenna to receive feeder link transmissions from a similarly high-gain transmitting antenna at the feeder link station in Montrose, Colorado. Linear polarization will be used on the feeder link to maximize frequency re-use by any future conventional U.S., Canadian and Mexican L-band FSS systems. Moreover, the use of high-gain, spot-beam feeder link antennas will permit even greater re-use of these same L-band frequencies by conventional Ka-band FSS systems serving the United States, even if the satellites in those systems are as close as two degrees from the satellites of CD Radio, Inc.

7. Launch Vehicle.

The exact weight and dimensions of the satellites for the CD Radio, Inc.'s system will depend on the specific designs proposed by spacecraft manufacturers in response to CD Radio, Inc.'s RFP. However, it is likely that the spacecraft will fall within the weight and volume limitations of a Titan 3C launch vehicle.

8. Eclipse Operation.

Semi-annual eclipse periods occur around the vernal and autumnal equinoxes. Those periods, centered around midnight at the sub-satellite longitude, increase from a few minutes each night for about 15 days, reach a maximum duration of about 72 minutes, and then decrease for another 15 days. Separating the satellites by 18 degrees means that the times of occurrence of eclipses at the two satellites will differ by 72 minutes. Thus, the two satellites will never be eclipsed simultaneously. Therefore, even if no batteries were carried aboard the satellites, 33 channels of programming would be provided by one satellite or the other in every part of the United States during the eclipse periods. But more channels will actually be provided by the CD Radio, Inc. system during eclipse periods. As discussed below, a portion of the weight saved by not having to carry fuel for inclination control, will be used to carry additional batteries for operation during eclipse.

The actual number of channels that will be provided will depend on the designs proposed by spacecraft manufacturers.

9. Orbit Parameter Accuracy and Antenna Pointing Accuracy.

Because of the inherently wide beams of satellite transmitters and typical receiving installations at these L-band frequencies, CD Radio, Inc. satellites do not need the same station-keeping accuracy as say, FSS satellites at 4&6 GHz and above. However, the satellites of CD Radio, Inc. will comply with Radio Regulations 2616-2619. The spacecraft will have the capability of maintaining their position within +/- 0.1 degree of the longitude of their nominal position. As required by RR 2619, they will maintain their position within those limits when it is necessary to prevent unacceptable interference to any other satellite network whose space station complies with those limits. When interference will not be caused to other satellites, CD Radio, Inc. satellites will be maintained within about +\- 1 degree of the longitude of their nominal position.

Inclination of the satellites will no greater than five degrees, throughout their operational lifetime. Those are the limits within which satellites must remain to be considered geostationary by the International Frequency Registration Board (IFRB) of the ITU. Satellites can maintain an inclination of less than five degrees for a period of more than 12 years, with out requiring the expenditure of any station-keeping fuel. That represents a considerable saving in payload which can be used for other, essential systems and subsystems such as batteries for eclipse operation. The technique for holding inclination to under five degrees for more than 12 years, is based on the fact that a satellite can be injected into the geostationary satellite orbit with an ascending node such that the inclination initially decreases at the rate of 0.8 degrees per year. If the satellites are placed in orbit with an initial inclination of 5°, and with the appropriate ascending node, the inclination will decrease to zero in about 6.25 years. Thereafter, inclination will increase inexorably at the same rate. Thus, after another 6.25 years, the inclination will again have reached five degrees, and will continue increasing until it reaches some stable, much higher (and useless) inclination. Therefore, the satellites will remain within the five-degree limit for two times 6.25 years, that is, for about 12-1/2 years.

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TELECOMMUNICATIONS SYSTEMS

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CERTIFICATION OF PERSON RESPONSIBLE FOR PREPARING ENGINEERING INFORMATION SUBMITTED IN THIS APPLICATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this application, that I am familiar with Parts 2, 25 and 73 and 87 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this application, and that it is complete and accurate to the best of my knowledge.

by: Richard G Gould

Richard G. Gould
Registered Professional Engineer

dated: May 17, 1990

Figure 1

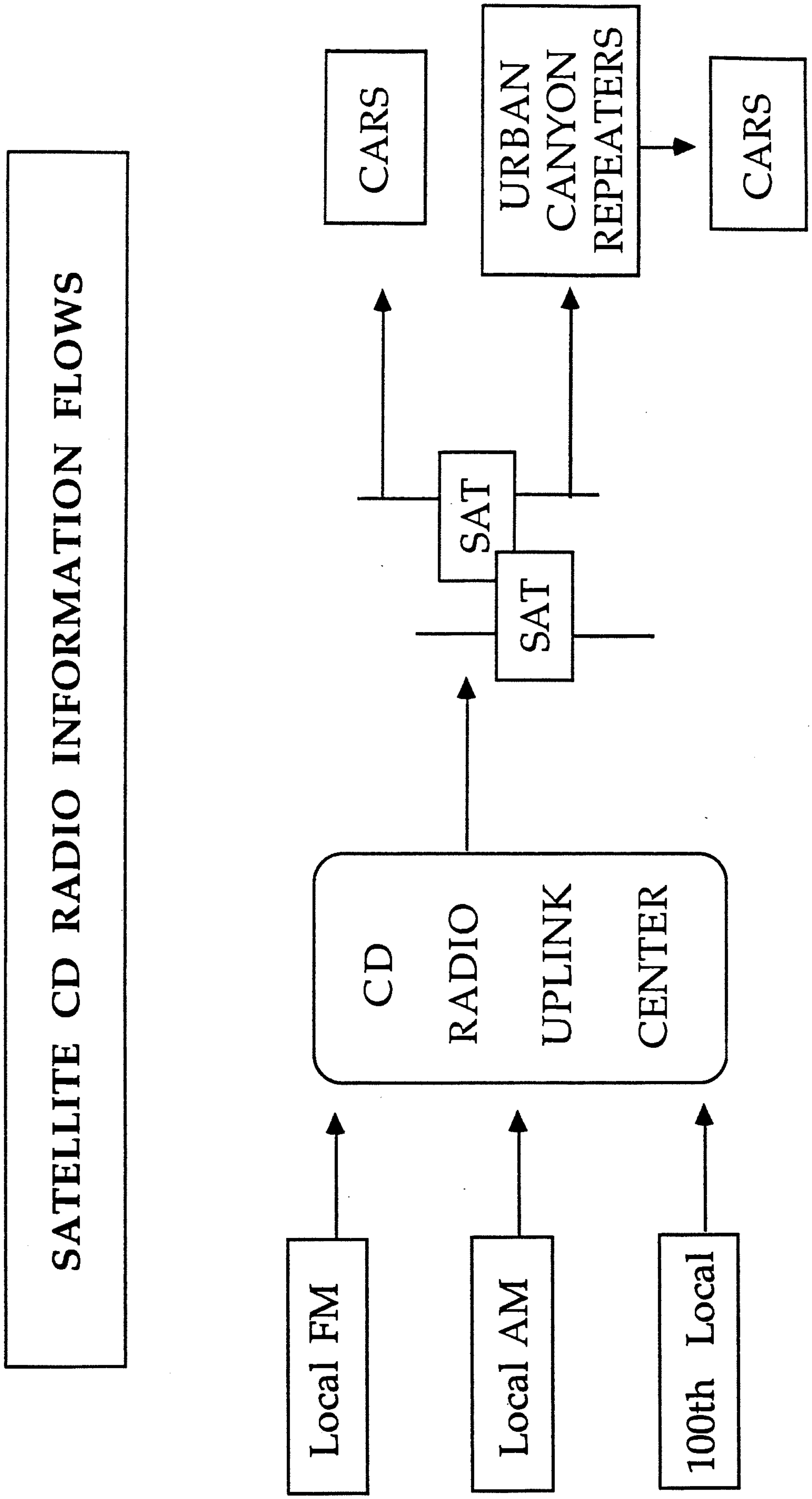
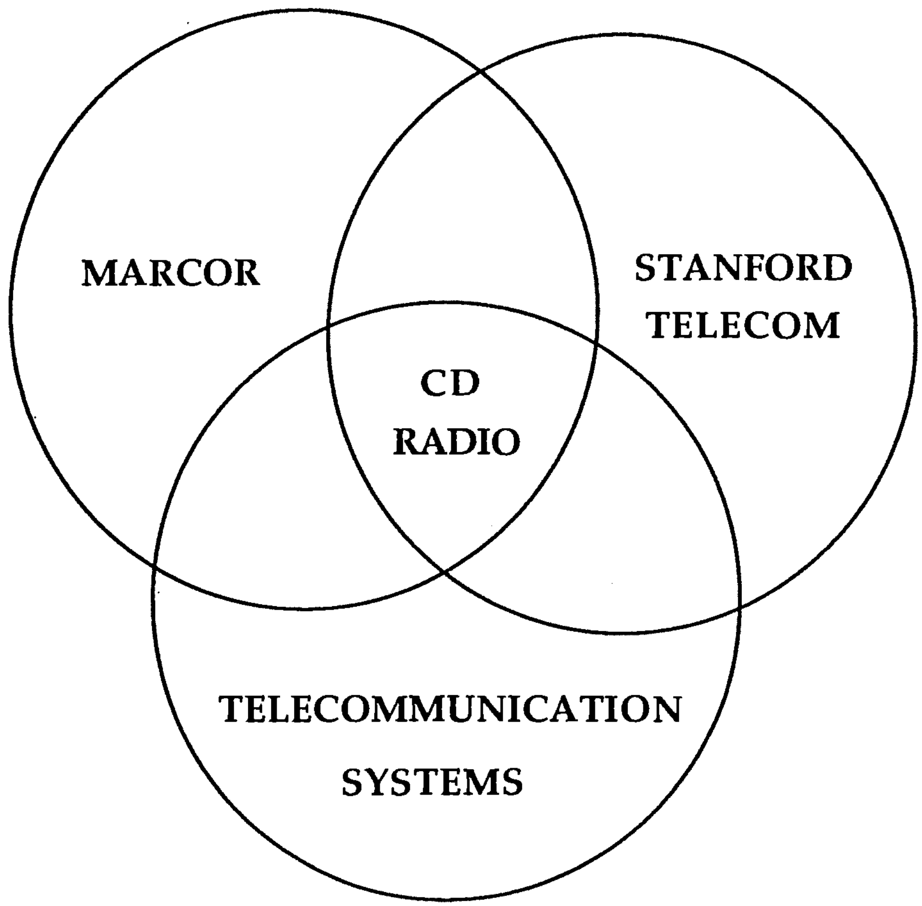

SATELLITE CD RADIO INFORMATION FLOWS
Local FM
Local AM
100th Local
CD RADIO UPLINK CENTER
SAT
SAT
CARS
URBAN CANYON REPEATERS
CARS

Figure 2

CD RADIO SYSTEM ENGINEERING



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 at 121° West Longitude	)	

APPLICATION OF SATELLITE CD RADIO, INC.
FOR A PRIVATE DIGITAL
SATELLITE SOUND BROADCASTING SYSTEM

Pursuant to Section 308, 309 and 319 of the Communications Act of 1934, as amended, 47 U.S.C. §§ 308, 309 and 319, Satellite CD Radio, Inc. (hereinafter referred to as CD Radio, Inc.) requests authority to construct, launch and operate a space station in the satellite sound broadcasting service at 121° West Longitude.

The technical information supporting this application is contained in the attached technical showing.

CD Radio, Inc.'s legal and financial qualifications are demonstrated in the Satellite System Proposal preceding this application. CD Radio, Inc. hereby incorporates by reference the legal and financial showings made therein.

WAIVER PURSUANT TO SECTION 304 OF THE COMMUNICATIONS ACT OF 1934

Pursuant to Section 304 of the Communications Act of 1934, CD Radio, Inc. waives any claim to the use of any particular frequency or of the electromagnetic spectrum as against the regulatory power of the United States because of the previous use of the same, whether by license or otherwise, and requests the grant of construction, launch and operating authority in accordance with this application.

REQUEST FOR WAIVER OF
SECTION 319(d) OF THE COMMUNICATIONS ACT

CD Radio, Inc. hereby requests a waiver of Section 319(d) of the Communications Act, as amended, with respect to the above-referenced application in order to proceed immediately with the construction of the system proposed therein. As set forth below, CD Radio, Inc. believes that the requested modifications are in the public interest, and it is prepared to accept the risk of initiating the proposed service pending final action by the Commission on its application.

CD Radio, Inc. is a pioneer in proposing a private, digital satellite sound broadcasting system. Concurrent with the above-referenced application, CD Radio, Inc. is filing a petition for rulemaking requesting the Commission to initiate a rulemaking proceeding to amend its Table of Frequency Allocations to allocate frequencies for the proposed satellite sound broadcasting system.

As demonstrated in its Petition for Rulemaking, there is currently an unfulfilled demand for high-quality radio service and for radio stations with nationwide coverage. That demand can be satisfied by CD Radio, Inc. using its proposed system. Early construction, launch and operation of the satellite sound broadcast system will maximize efficient use of the spectrum by permitting early initiation of the service and further refinement in light of practical experience derived from the system's operation. Interim service is critical to demonstrate the commercial viability of the system and to bring competition to the broadcast and developing cable radio markets. Rapid introduction of the satellite sound broadcast service would help ensure effective competition to the emerging provision by cable systems of radio services by providing a high-quality radio alternative. Thus, the Commission's goal of diversifying sources of radio programming would be promoted.

For these reasons, CD Radio, Inc. requests that the Commission grant a waiver of Section 319(d) of the Communications Act to permit construction to begin as soon as possible. CD Radio recognizes that any expenditures made pursuant to this waiver will be at CD Radio's risk and that the grant of this waiver will not prejudice the Commission's final decision regarding the merits of CD Radio's application.

CERTIFICATION

The undersigned, individually and for the applicant, hereby certifies that the statements made in this application are true, complete, and correct to the best of his knowledge and belief, and are made in good faith.

Respectfully submitted,

SATELLITE CD RADIO, INC.

By: ______________________
Peter Dolan
President

May 18, 1990

Technical Appendix

1. Introduction.

CD Radio, Inc. is applying for authority to operate a domestic sound broadcasting-satellite system with downlinks in the L-band and feeder links in the Ka-band, pursuant to Sections 308, 309 and 319 of the Communications Act as amended. The complete CD Radio, Inc. system will consist of two operational satellites, a multiplicity of terrestrial repeaters primarily serving permanent urban areas of the country, and an earth station which provides feeder links to the satellites, and performs the functions of tracking, telemetry and control of the spacecraft.

A newly developed audio processing technique will contribute to the high spectrum efficiency and cost-effectiveness of the overall system.

This transmission format Offset Quadrature Phase Shift Keying ("OQPSK") at a bit rate of 256 kb/s, will be used for satellite transmissions, for terrestrial repeaters of those transmissions, and by independent terrestrial broadcasting stations that will be operating in an adjacent frequency band. Therefore, the home, portable and vehicular radio sets to be used with this new broadcasting service will be able to pick up 100 satellite and terrestrial broadcasting channels of CD-quality, stereophonic nationwide, regional and local programming throughout the United States.

2. General Description.

The two satellites in the CD Radio, Inc. system will be spaced 18 degrees apart at 103° and 121° west longitude to provide undiminished service from one satellite at all times during eclipse periods. On-board batteries will enable the satellite to carry a substantial number of its 99 channels throughout its period of eclipse.

To provide CD-quality audio programming throughout the continental United States, the country will be divided into three regions, designated Eastern, Central and Western. Each satellite will have three antenna beams of approximately three degrees each, providing coverage of those regions, as shown in Figure 1.

Each satellite will provide a total of 99 channels, 33 channels in Eastern, Western and Central Beams. Thus, the two satellites together will provide a total of 66 channels to the Eastern, Western and Central Regions of the U.S. The transponders connected to the Central Beam will have nominal e.i.r.p. of 46.1 dBW, while the transponders connected to the

Eastern and Western Beams will each have a nominal e.i.r.p. of 46.4 dBW. The slightly higher e.i.r.p. in the Eastern and Western Beams is intended to compensate for higher signal attenuation in those regions of the country with heavier foliage.

Each of the three transmitting beams will have a beam width of approximately three degrees, and hence, a gain of about 34.8 dBi. However, careful beam shaping (as shown in Figure 1) and power weighting will be employed both to confine the transmitted power to the desired more or less rectangular service areas, and to hold the difference in power between beam center and beam edge to about 1.5 dB (a difference which would otherwise be 3 dB).

The satellites will employ a reflector-type antenna with a multiplicity of feeds to generate the shaped coverage patterns mentioned above. This arrangement provides for the addition "in space" of the power from individual, moderate-size solid-state power amplifiers.

Satellites will be procured from spacecraft manufacturers responding to a Request for Proposal (RFP) that will set forth overall performance specifications, rather than detailed design specifications. In that way, CD Radio, Inc.'s system can benefit from the best and latest technology available to the international satellite industry, and tailored to CD Radio, Inc.'s specific requirements. Therefore, specific details of the spacecraft design are not known at this time. However, it is likely that the proposed spacecraft will be three-axis stabilized, with attitude-control being effected by a combination of earth sensors, gyros, inertia wheels and hydrazine thrusters.

The prime power required for all the L-band fixed power amplifiers, will be 6600 watts. Power requirements for other communication sub-systems and for housekeeping functions will bring the overall satellite power requirement to about 9,000 watts. Spacecraft weight in orbit will be about 2400 kg (5280 pounds). The satellites are intended to be launched on a Titan 3C launch vehicle.

3. <u>Number and Location of Earth Stations.</u>

Millions of home, portable and vehicular receivers will be used at arbitrary locations throughout the United States. Signal specifications will be common among transmissions from CD Radio, Inc.'s satellites, from the terrestrial repeaters re-transmitting those same signals, and from the independent broadcasting stations that will be operating in an adjacent frequency band. CD Radio, Inc. will provide the signal and format specifications, and will render other assistance and furnish information to prospective receiver manufacturers to ensure equipment compatibility, but will have no other involvement with receiver production, ownership or operation.

CD Radio, Inc. will operate a combined feederlink and TT&C station near Montrose, Colorado. This location has been chosen because of its extremely low annual rainfall, and because it is in an area of low geological activity.

The station design concept is based on redundancy in all transmitting and receiving systems to maintain program continuity monitoring and control functions in the event individual system elements fail. For example, the station will have two, operating high-gain feeder link antennas: each transmitting to one of the satellites. A third feeder link antenna, with a completely redundant transmitter chain, will be on hot standby, to be used in the event of a failure of one of the operating feeder link chains, as well as to permit the performance of periodic maintenance.

4. Communication Subsystem.

4.1. GENERAL. The design of CD Radio, Inc.'s communication subsystem is based on the latest digital audio technology. The features of this design include:

- Stereo compact disk audio quality directly to the listener by the use of a spectrum-efficient, digital sound encoding technique developed by Dolby Laboratories.
- A system design that permits the production of a series of receivers whose cost and complexity depend only on the type of environment in which the receiver is intended to operate.
- A system design that does not constrain all consumer receivers to be of high complexity and cost.
- The use of adaptive equalization in vehicular receivers to simultaneously mitigate the effects of delay spread and to optimally utilize the signal power that does exist in the delay spread multipath signal.
- The use of quad-spatial diversity in vehicular receivers to mitigate the effects of multipath fading.
- The use of high power terrestrial repeaters to ensure the availability of uncompromised, high quality CD radio service in heavily shadowed urban areas.
- Efficient use of the spectrum through the paired use of frequencies assigned to specific satellite beams for terrestrial repeaters.
- A design that permits program channels to be added to the satellite as service providers are added to the system. This leads to the efficient use of the spectrum and of satellite transmitter power if programming and sponsors are only available for a fewer number of channels. This is in contrast to alternative system designs in which channels must be added in blocks of 8 or 16. For example, if all channels in existing blocks were assigned, then to add

an additional channel would require the addition of a new block and the power and bandwidth to transmit all 8 or 16 channels.

4.2 DOWNLINK BUDGET. A downlink budget for the satellite-based links of the CD Radio, Inc. system serving the contiguous 48 states (Conus) is given in Table 1. There will be two satellites in the geostationary orbit transmitting at 1500 MHz and using Offset Quadrature Phase Shift Keyed (OQPSK) modulation with a bit rate of 256 kbps per stereo program channel. Channel coding, in the form of a rate 1/2, constraint length 7 convolutional code, will be applied to each program channel as a means to mitigate the effects of shadowing and multipath and to efficiently use the satellite transmitter power [1], [2]. The use of convolutional coding will double the symbol rate of the OQPSK carrier to 256 ksps.

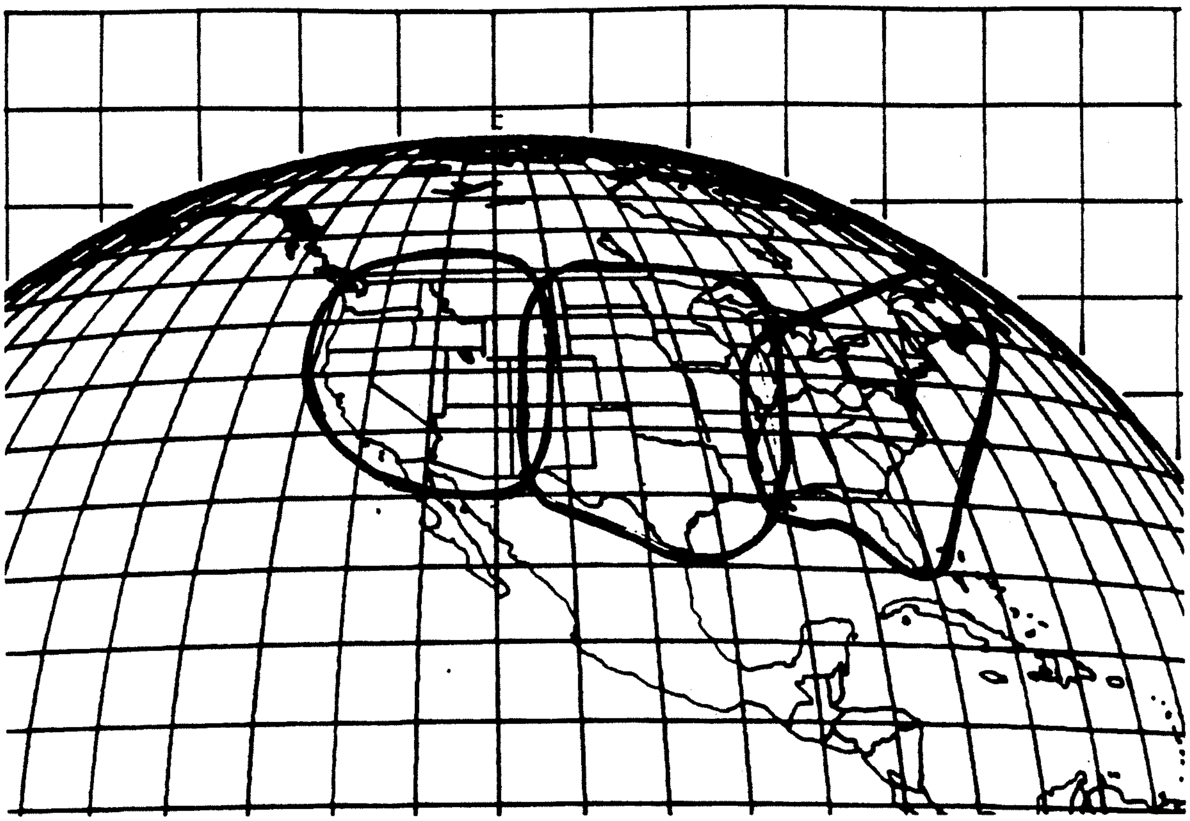
4.3 SYSTEM COVERAGE. As shown in Figure 1, Conus coverage will be provided by three shaped satellite transmitting antenna beams to cover three major geographical areas: one of each of the beams will cover the eastern, central, and western portions of the US. As indicated by the entries in Table 1, somewhat less power will be apportioned to serve the central part of the US since the amount of foliage, and thus shadow loss, in this area of the US is less than in other areas.

The two satellites will be located at 103° and 121° West longitude. Each satellite will provide 33 channels in the Eastern, Western and Central Beams, for a total of 66 channels in each beam area provided via satellite. Another 34 channels in each beam area will be provided by high-power terrestrial transmitters to provide coverage in "urban canyons," that is, in heavily populated areas where buildings may block line-of-sight from the satellites.

Table 1: CD-Radio link budget

Parameter	Units	Central Beam	East and West Beam
Transmitter Power	(Watts)	16.0	17.0
	(dBW)	12.0	12.3
Filter, cable and VSWR loss	(dB)	-0.7	-0.7
Transmitting antenna diameter	(m)	4.7	4.7
Transmitting antenna gain	(dBic)	34.8	34.8
Antenna 3 dB beamwidth	(Deg)	3.0	3.0
E.i.r.p.	(dBW)	46.1	46.4
Power variation within shaped beam	(dB)	-1.5	-1.5
Path loss	(dB)	-187.7	-187.7
Spectral pfd	(dBW/m^2 4kHz)	-131.6	-131.4
Polarization loss	(dB)	-0.5	-0.5
Receiving antenna gain	(dBic)	5.0	5.0
Receiver noise temperature	(K)	100.0	100.0
Elevation angle	(deg)	30.0	30.0
Antenna noise temperature	(K)	50.0	50.0
Receiving system temperature	(K)	150.0	150.0
Adjacent channel interference	(dB)	-0.5	-0.5
Demodulator loss	(dB)	-0.5	-0.5
Mean received Eb/No	(dB)	14.2	14.5
Theoretical Eb/No (BER=10^{-6})	(dB)	7.0	7.0
Required Eb/No (BER=10^{-6})	(dB)	8.0	8.0
Margin (For any excess path loss and all other factors)	(dB)	6.2	6.5

Figure 1: Satellite coverage areas.



With the satellites positioned at 103° and 121° West longitude, the minimum elevation angle will be on the order of 30°. The link budget in Table 1 shows that within the coverage area there will be a minimum link margin in excess of 6 dB to account for such factors as excess path loss due to shadowing.

4.4 TYPES OF SERVICES. CD Radio, Inc. system is designed to provide 66 compact disk-quality stereo broadcast channels to the general population while in their homes or places of business, while engaged in outdoor activities, or while in their vehicles. It is intended to be a totally new and ubiquitous service.

The system incorporates a high-quality audio transform encoding technique developed by Dolby Laboratories that is known as the Dolby AC-2 audio coding process. At 128 kbps per monaural channel (256 k samples/sec for stereo), which is one-sixth the bit rate of 48 k samples/sec 16-bit PCM, it produces a virtually transparent signal fidelity even when operating with a bit error ratio as high as 10^{-5} [ref. 3]. The salient performance characteristics of the CD coding process are summarized in Table 2 [ref. 4].

Table 2: Characteristics of the Dolby AC-2 digital audio coders/decoders.

Response	20 Hz to 15 kHz ±0.2 dB
Distortion	Less than 0.1% at 1 kHz Less than 0.4%, 20 Hz - 15 kHz
Dynamic Range	Greater than 90 dB
Crosstalk	Less than -80 dB
Level Stability	Better than 0.2 dB
Coding Method	Dolby AC-2
Audio Sampling Rate	48 k samples/second
Data Clock	256 kHz ±25 ppm
Error Correction	Reed-Solomon
Time Delay	45 ms, encode-decode, including formatting delay

A 1200 bps auxiliary data channel is also provided by the Dolby AC-2 digital audio coder/decoder; use of this channel has no effect on the performance of the main audio channels.

4.5 MODULATION PARAMETERS. The CD Radio, Inc. system uses a spectrum-efficient, power-efficient, constant-envelope, single carrier per stereo channel modulation method. The 256 kbps binary data stream from the output of the Dolby AC-2 encoder is encoded using a rate 1/2, constraint length 7, convolution code. The output, which is at a serial data rate of 512 kbps, is fed to a modulator which generates an offset quadrature phase shift keyed signal (OQPSK) with a symbol rate of 256 ksps. The advantage of OQPSK, in comparison with QPSK (i.e., 4-Phase PSK), is less regeneration of the "tails" of the RF spectrum of the signal after amplification in a non-linear amplifier, such as solid-state power amplifiers (SSPA) and traveling wave tubes (TWT), which exhibit AM to AM and AM to PM distortion [5]. Minimizing the energy in the spectral "tails" promotes efficient use of the spectrum and reduces the amount of adjacent channel interference.

5. Consumer Receiver Parameters.

5.1 GENERAL. The philosophy employed in the design of the CD Radio, Inc. system permits a range of receivers to be marketed, whose cost and performance reflect the environment in which the receivers are intended to operate. All receivers will be capable of being tuned over the frequency bands assigned to the satellite channels, terrestrial repeaters, and the terrestrial broadcast channels. There will be complex receivers that are intended to operate in the most severe propagation environment - the heavily shadowed, delay-dispersive urban environment. Unlike alternative satellite sound broadcasting system designs that are described in [6], the CD Radio, Inc. system also permits the marketing of simple receivers intended to operate in the least harsh environment. A minimum of four different types of consumer receivers are presently envisaged for use with the CD Radio, Inc. system. The characteristics of these receivers are summarized in Table 3.

Table 3: Receiver characteristics

TYPE	CHARACTERISTICS
- Home, fixed	- Single outdoor antenna
	- Single-channel receiver
	- Simple convolutional code decoder
- Portable, for signal level urban areas	- Single antenna (no space use in high- diversity)
	- Single-channel delay equalizer
	- Simple convolutional code decoder
- Portable, for signal level urban areas	- Dual antenna (dual space use in low- diversity)
	- Dual-channel delay equalizer
	- Viterbi maximum likelihood decoder
- Vehicular	- Quad antenna (quad space diversity)
	- Four-channel delay equalizer
	- Viterbi maximum likelihood decoder

The home receiver intended for fixed operation with an attic or outdoor antenna is the least expensive. It features a single antenna of moderate gain (e.g., 10 dBic) pointed towards either the satellite or the local terrestrial repeater. The receiver uses a single RF channel, since space diversity is not used. The receiver also employs a simple, majority-logic convolutional decoder, since the coding gain afforded by the use of a Viterbi maximum likelihood decoder is not needed.

The portable receiver for use in high-signal level urban areas will have some of the same features as the home receiver. Specifically, since the receiver will be operating in high-signal level environment, a single antenna and single RF channel receiver will suffice. However, because of the delay-spread of the signals in an urban environment, the receiver would contain an adaptive delay equalizer capable of accommodating multipath signals with delays up to 40 usec. This is to be contrasted with alternative system designs described in CCIR Report 955-1 (MOD F) [2] which can only accommodate delays up to 16 usec.

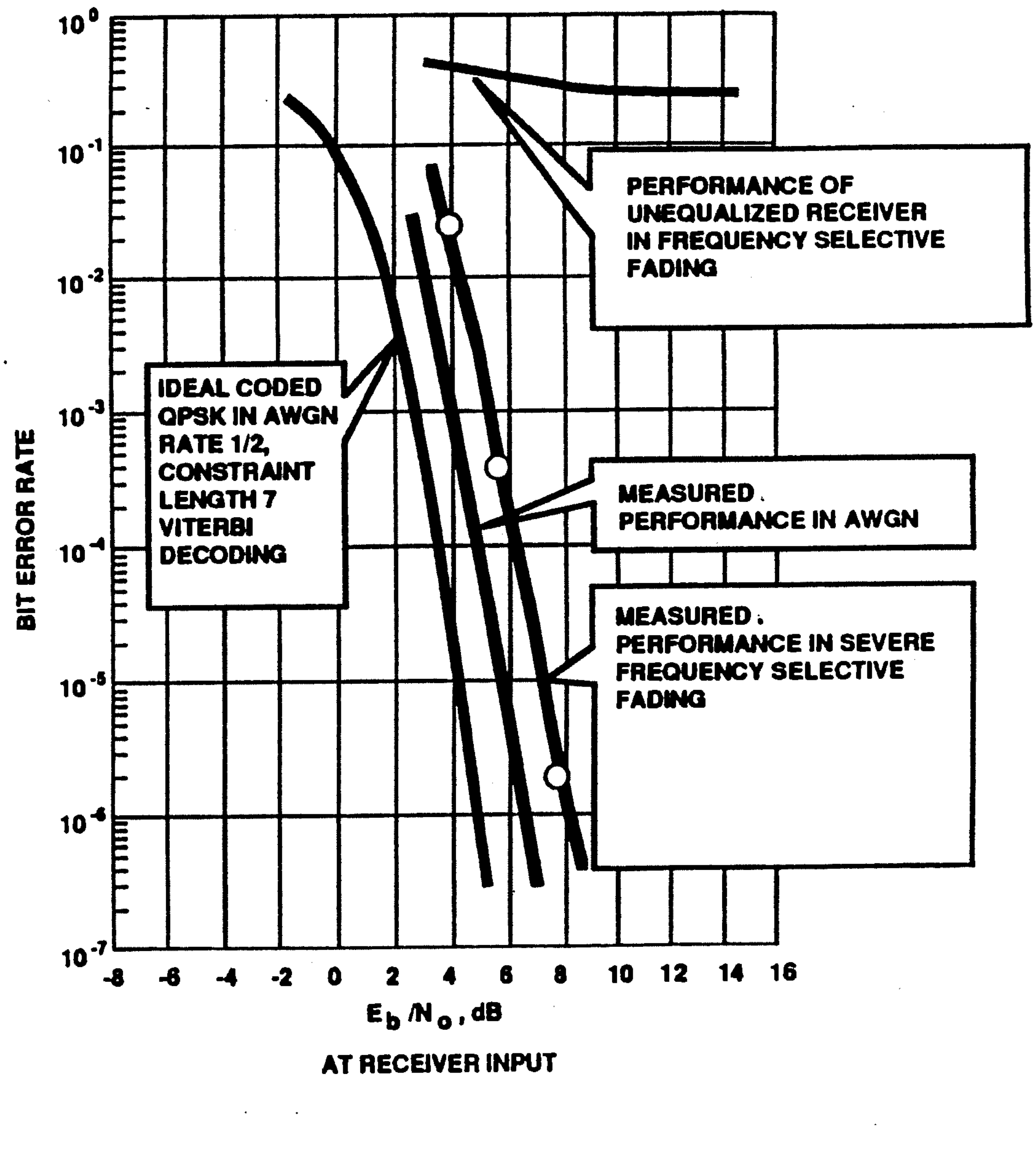
The next level of complexity is characterized by the portable receiver intended for operation in a low-signal level urban environment. This type of receiver uses dual space diversity to minimize fading and a Viterbi maximum likelihood decoder to realize a coding gain of about 5 dB at a BER of

10^{-6}. Space diversity requires a two-channel receiver with dual diversity antennas.

The vehicular receiver will be the most complex since it will operate in the most harsh propagation environment: the multipath fading, low-signal level, delay dispersive urban environment. This receiver uses quad-space diversity with maximal ratio combining, a four-channel adaptive delay equalizer, and Viterbi maximum likelihood decoder.

The technology for these receivers is well in hand. Viterbi maximum likelihood decoders are available from several sources, including Stanford Telecommunications [7]. A receiving system featuring triple-space diversity, maximal ratio combining, and adaptive equalization has been demonstrated by Stanford Telecommunications [8]. The measured performance of the receiver in a severe frequency-selective fading environment as shown in Figure 2, dramatically illustrates the performance gain achieved by using adaptive equalizers.

Figure 2: Performance in severe frequency-selective fading environment.



5.2 RECEIVING ANTENNAS. A variety of receiving antennas will be used in the CD Radio, Inc. system. All of the antennas will be circularly polarized. For fixed installations, such as homes and office buildings, a multi-turn helical antenna exhibiting a gain of about 10 to 12 dBic would be mounted outside or in the attic, and, depending on the relative signal level in the service area, pointed either towards the satellite or towards the terrestrial transmitter.

Portable receivers would use either a single element or a collinear array of circularly polarized, crossed drooping dipoles with half-wavelength elements. These elements exhibit a gain of about 5 dBic. Alternatively, a planar, circularly polarized micro-strip patch antenna, which also exhibits a gain of about 5 dBic and is a half-wavelength on a side, could be used. The physical dimensions of these antennas are on the order of 10 cm for an operating frequency of 1500 MHz.

Vehicular antennas will comprise four, collinear crossed drooping dipole elements to provide for quad-spatial diversity. These elements must be separated by at least one-half wavelength to ensure that the signals received by each element will fade independently. Based on the separation requirement, the height of the array will be on the order of two wavelengths, or 40 cm.

The receiver low-noise amplifier is a High Electron Mobility Transistor (HEMT) device exhibiting an operating noise temperature of 100 K. The antenna noise temperature, for crossed drooping antennas, is expected to be on the order of 50 K based on measurements performed in rural and suburban areas [9].

6. Radio Frequency Plan & Polarization.

6.1 GENERAL. Frequencies in the range 1470-1530 MHz will be used for satellite transmissions. This band of 60 MHz can provide 200 channels of 300 kHz each. About one-third of the band, or 19.8 MHz, which can provide 66 channels of 300 kHz each, will be designated for use in each of the regional beams.

By using contiguous blocks of frequencies for each beam, frequency re-use by neighboring countries is facilitated. Moreover, as satellite antenna technology is improved in future years, to permit even smaller beams at these L-band frequencies, the three regions of the United States can be subdivided (as in a terrestrial cellular system) and the blocks re-used within regions.

Circular polarization will be used on the downlinks.

6.2 TERRESTRIAL REPEATERS. Terrestrial repeaters will be provided as an integral part of the CD Radio system. The use of repeaters ensures the availability of uncompromised, CD-quality stereo broadcasting service in heavily shadowed urban areas that would otherwise receive weak signals.

The CD Radio frequency plan is based on a reuse factor of 3. Thus, each of the satellite beams is assigned 1/3 of the total available satellite spectrum. Within each of the satellite beam areas, the remaining frequencies are available for use by the terrestrial repeaters (except in areas where the satellite beams overlap one another). In the overlap areas, only one set of the frequencies is available on a non-interfering basis. As an example, consider three blocks of frequencies. One-third of the frequencies will be assigned to each block, F1, F2, and F3. Each of the 66 program channels will be associated with a specific 300 kHz bandwidth channel in each frequency block. In each region of the country, one of the blocks will be used for the satellite transmissions and the other blocks will be used for terrestrial transmitters.

Frequencies for terrestrial transmitters must be chosen so that there is no interference from the same frequency used for a satellite channel in the adjacent beam.

In other words, if frequency block F2 is used in the Central beam, channels from block F1 could be used for terrestrial transmitters in that same Region, except in its western parts where satellite signals from the Western Beam (which also uses Block 1) can be received. Similarly, channels from Block 3 could be used for terrestrial transmitters in the Central Region, except in its Eastern portions, where signals from the Eastern Beam (which also uses Block 3) can be received.

The radiated power of the repeater will be on the order of 30 dBW to 40 dBW per stereophonic channel. The repeater site will be selected to permit the transmitting antenna to be mounted sufficiently high to provide the desired coverage. The antenna will generally be circularly polarized and have an omnidirectional pattern with 5 dBic gain. This will provide service to a vehicular receiver at distances on the order of 20 km.

The modulation format and audio coding of the signal transmitted by the repeater will be identical to that used on the satellite broadcasting channel.

The consumer receivers incorporate circuitry to sample the signals received on the selected channel in blocks 1, 2, and 3 and after a sufficient number of samples, to switch to the block which has the strongest signal.

6.3 FEEDER LINKS. Feeder links will operate in the L-band now allocated to the FSS (Earth-to-space), that is, in the range 27.5-29.5 GHz. Satellites will utilize "bent-pipe" transponders, that is those employing simple frequency-translation. Thus, the same bandwidth will be required for feeder links, 60 MHz.

Each of the satellites will use a single, high-gain receiving antenna to receive feeder link transmissions from a similarly high-gain transmitting antenna at the feeder link station in Montrose, Colorado. Linear polarization will be used on the feeder link to maximize frequency re-use by any future conventional U.S., Canadian and Mexican L-band FSS systems. Moreover, the use of high-gain, spot-beam feeder link antennas will permit even greater re-use of these same L-band frequencies by conventional Ka-band FSS systems serving the United States, even if the satellites in those systems are as close as two degrees from the satellites of CD Radio, Inc.

7. Launch Vehicle.

The exact weight and dimensions of the satellites for the CD Radio, Inc.'s system will depend on the specific designs proposed by spacecraft manufacturers in response to CD Radio, Inc.'s RFP. However, it is likely that the spacecraft will fall within the weight and volume limitations of a Titan 3C launch vehicle.

8. Eclipse Operation.

Semi-annual eclipse periods occur around the vernal and autumnal equinoxes. Those periods, centered around midnight at the sub-satellite longitude, increase from a few minutes each night for about 15 days, reach a maximum duration of about 72 minutes, and then decrease for another 15 days. Separating the satellites by 18 degrees means that the times of occurrence of eclipses at the two satellites will differ by 72 minutes. Thus, the two satellites will never be eclipsed simultaneously. Therefore, even if no batteries were carried aboard the satellites, 33 channels of programming would be provided by one satellite or the other in every part of the United States during the eclipse periods. But more channels will actually be provided by the CD Radio, Inc. system during eclipse periods. As discussed below, a portion of the weight saved by not having to carry fuel for inclination control, will be used to carry additional batteries for operation during eclipse.

The actual number of channels that will be provided will depend on the designs proposed by spacecraft manufacturers.

9. Orbit Parameter Accuracy and Antenna Pointing Accuracy.

Because of the inherently wide beams of satellite transmitters and typical receiving installations at these L-band frequencies, CD Radio, Inc. satellites do not need the same station-keeping accuracy as say, FSS satellites at 4&6 GHz and above. However, the satellites of CD Radio, Inc. will comply with Radio Regulations 2616-2619. The spacecraft will have the capability of maintaining their position within +/- 0.1 degree of the longitude of their nominal position. As required by RR 2619, they will maintain their position within those limits when it is necessary to prevent unacceptable interference to any other satellite network whose space station complies with those limits. When interference will not be caused to other satellites, CD Radio, Inc. satellites will be maintained within about +\- 1 degree of the longitude of their nominal position.

Inclination of the satellites will no greater than five degrees, throughout their operational lifetime. Those are the limits within which satellites must remain to be considered geostationary by the International Frequency Registration Board (IFRB) of the ITU. Satellites can maintain an inclination of less than five degrees for a period of more than 12 years, with out requiring the expenditure of any station-keeping fuel. That represents a considerable saving in payload which can be used for other, essential systems and subsystems such as batteries for eclipse operation. The technique for holding inclination to under five degrees for more than 12 years, is based on the fact that a satellite can be injected into the geostationary satellite orbit with an ascending node such that the inclination initially decreases at the rate of 0.8 degrees per year. If the satellites are placed in orbit with an initial inclination of 5°, and with the appropriate ascending node, the inclination will decrease to zero in about 6.25 years. Thereafter, inclination will increase inexorably at the same rate. Thus, after another 6.25 years, the inclination will again have reached five degrees, and will continue increasing until it reaches some stable, much higher (and useless) inclination. Therefore, the satellites will remain within the five-degree limit for two times 6.25 years, that is, for about 12-1/2 years.

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TELECOMMUNICATIONS SYSTEMS

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CERTIFICATION OF PERSON RESPONSIBLE
FOR PREPARING ENGINEERING INFORMATION
SUBMITTED IN THIS APPLICATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this application, that I am familiar with Parts 2, 25 and 73 and 87 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this application, and that it is complete and accurate to the best of my knowledge.

by: Richard G Gould

Richard G. Gould
Registered Professional Engineer

dated: May 17, 1990

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 Space Stations in the Satellite Sound Broadcasting Service	)	

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

Peter Dolan
President

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(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.