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(71) Applicant *(for all designated States except US)*: **XM SATELLITE RADIO INC.** [US/US]; 1500 Eckington Place NE, Washington, District Of Columbia 20002-2194 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **DE BASTOS, Derek** [US/US]; 21108 Golf Estates Drive, Laytonsville, Maryland 20882 (US). **NGUYEN, Duy** [US/US]; 22233 Silverpointe Loop, Corona, California 92883 (US).

(74) Agents: **LONGANECKER, Stacey** et al.; Roylance, Abrams, Berdo & Goodman L.L.P., 1300 19th Street, NE, Suite 600, Washington, DC 20036 (US).

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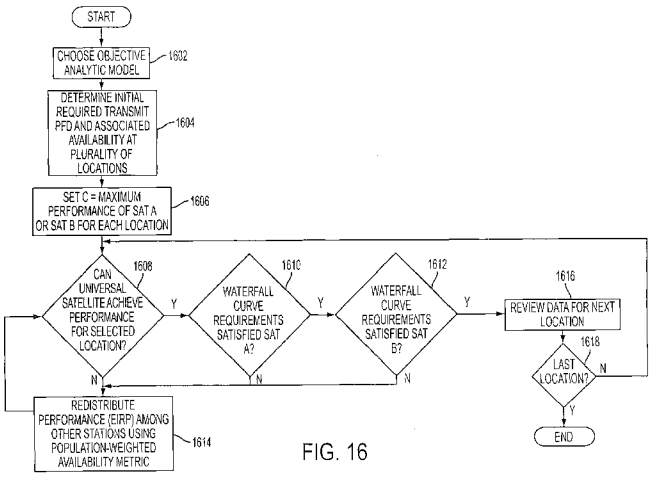


FIG. 16

(57) **Abstract:** A system is provided for configuring a universal transmit antenna for a geostationary satellite that produces a near-equal effective-isotropic-radiated-power (EIRP) pattern, independent of the orbital location in which the satellite is positioned. In a satellite broadcast system employing spatial diversity with two satellites (e.g., satellites positioned at 85° West and 115° West), the universal antenna operates on a cost-effective in-orbit spare satellite since the spare satellite with universal antenna can be positioned at either satellite location, thereby saving in capital investment and in time to construct the spare satellite. Predicted combined availability due to the in-orbit spare satellite and one satellite having an optimized antenna is comparable to that achieved when optimized antennas are employed in both satellites for use in respective orbital locations.

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Patent Application

for

METHOD AND APPARATUS FOR CONFIGURING UNIVERSAL TRANSMIT ANTENNA FOR USE ON SPARE SATELLITE IN A MULTIPLE SATELLITE SYSTEM

by

Derek de Bastos

and

Duy N. Nguyen

Field of the Invention

[0001] The present invention is directed to satellite transmit antenna analysis, design and optimization. More particularly, the present invention is directed to a system for and method of optimizing and configuring a universal antenna for use on a spare satellite for any satellite in a multiple satellite system. Further, the present invention is directed to a system for and method of optimizing and configuring a universal antenna for use on a spare satellite for any plural deployed satellites that use spatial diversity transmission techniques to minimize outages at ground-based receivers and for which two or more antenna patterns projected from respective satellites have been jointly optimized.

Background of the Invention

[0002] The Federal Communications Commission has approved the use of selected radio frequency spectrum for satellite radio broadcasting. Satellite radio broadcasting delivers 100 or more channels of audio content to ground-based stationary or mobile radio receivers that may be installed in vehicles such as cars, boats, and the like, or implemented as portable or non-portable radio receivers such as

a receiver for use with a stereo receiver, or receiver embodied in a clock-radios or mobile telephone, and so on.

[0003] One implementation for a broadcast segment of a satellite radio system comprises two geostationary satellites at 85° and 115° West longitude orbital locations. In these orbits, virtually every location in the contiguous United States (CONUS) has a direct view of both satellites. In an exemplary implementation of the broadcast segment, described in detail in U.S. Ser. No. 09/318,938, filed May 26, 1999, now U.S. Pat. No. 6,154,452 entitled "METHOD AND APPARATUS FOR CONTINUOUS CROSS-CHANNEL INTERLEAVING," and U.S. Ser. No. 09/433,861, filed Nov. 4, 1999, entitled "METHOD AND APPARATUS FOR CONCATENATED CONVOLUTIONAL ENCODING AND INTERLEAVING," now U.S. Pat. No. 6,229,824 (both of which are incorporated herein in their entireties by reference), two satellites employ diversity broadcasting techniques, which rely on interleaving signals on each satellite so that, in the event one satellite becomes blocked momentarily due to terrain or buildings in an urban setting, the radio receiver can still decode the intended transmission and make the signal available for listening via speakers or headphones. Stated differently, the two cited references describe methods and apparatuses for implementing a satellite broadcasting system that uses spatial diversity techniques to minimize outages to radio receivers, particularly mobile radio receivers.

[0004] By having at least two satellites transmit different yet related signals that are both received and decoded, and thereafter combined in accordance with the aforementioned references by a single radio receiver, the chances that the intended transmission is actually received and properly played for a listener are greatly increased. This is especially important for mobile radio receivers that may encounter frequent, yet relatively brief blockages. However, in order to fully exploit the advantages of employing two satellites that employ spatial diversity techniques to enhance the chances of receiving the intended transmissions, it is important to provide high availability for each of the satellites.

[0005] Commonly-owned U.S. Patent No. 6,470,058, to Michalski et al, which is also incorporated by reference herein in its entirety, describes a method of jointly optimizing transmit antenna patterns of two geostationary satellites in a satellite broadcast system. In the illustrative embodiment described therein, the broadcast system employs two satellites positioned at 85° and 115° West longitude to provide a spatial diversity transmission technique to minimize outages at ground-based receivers. Transmit antennas of each satellite are optimized exclusively for the corresponding, intended orbital location. Further, the system employs the Extended Empirical Roadside Shadowing (EERS) model available from the *Handbook of Propagation Effects for Vehicular and Personal Mobile Satellite Systems*, NASA Reference Publication 1274, 2nd ed., Ch. 3.3, 11 Dec 1998 by Julius Goldhirsh and Wolfhard Vogel, which is incorporated herein by reference, to calculate the satellite link availability.

[0006] To ensure continuous service in an event of an in-orbit anomaly and future service expansion, a third satellite (hereinafter referred to as the spare satellite) is needed. Ideally, the spare satellite would be equipped with a transmit antenna that is optimized for launch and use in the orbital location of the particular satellite to be replaced. However, the economic factor is prohibitively high since at least two sets of antennas must be constructed simultaneously to provide a spare for both of the orbital locations (e.g., 85° and 115° West longitude) and, even if the construction cost is affordable, construction time may not be sufficiently fast to meet the necessary launch schedule. Furthermore, any spare satellite that is to be stored "in-orbit" (versus a spare to be stored "on ground") requires an antenna configuration that is capable of supporting both orbital positions.

[0007] Commercial satellites exist that employ sophisticated electronically-phased array antennas to achieve in-orbit reconfigurability to the broadcast system described above (e.g., as much as 30° of spatial separation). These satellites, however, can be prohibitively expensive to use as one or more spare satellites.

[0008] Thus, a need exists for a cost-effective spare satellite and method of configuring same prior to deployment for use in any of plural satellite orbital

locations employed for spatial diversity. Further, a need exists for such a spare satellite that provides combined availability (i.e., when used with one satellite having an optimized antenna for its location) that is comparable to that achieved when optimized antennas are employed in both satellites for use in their respective orbital locations.

Summary of the Invention

[0009] It is therefore an object of the exemplary embodiments of the present invention to provide a system for and a method of optimizing a universal or spare antenna that, when deployed on a replacement satellite, achieves acceptable system availability when used in conjunction with the at least one other satellite for which the antenna patterns of the one other satellite and the replaced satellite have been jointly optimized achieve a maximum combined availability across a predefined geographic region.

[0010] It is another object of the exemplary embodiments of the present invention to provide a system for and a method of calculating the most desirable antenna pattern for a universal or spare antenna that can replace one of at least two satellites in a satellite broadcasting system that employs spatial diversity broadcasting techniques.

[0011] In accordance with another aspect of the exemplary embodiments of the present invention, the antenna pattern of the universal antenna is shaped, tuned or adjusted to provide uniform high availability to terrestrial radio receivers, when deployed on the replacement satellite and used in conjunction with a jointly optimized satellite, without wasting power where it is not needed.

[0012] Thus, method is provided for optimizing an antenna pattern for a universal antenna to replace either of first and second antennas on respective ones of first and second satellites that have been deployed in first and second orbital positions and configured to operate in conjunction with each other to deliver signals to each of a plurality of receivers in a selected geographic coverage area having differing line of sight elevation angles to each of the first and second satellites. The method comprises

(1) determining, for each of a plurality of reference locations in the selected geographic coverage area, an initial performance value; (2) determining a population weighted average availability using first and second availability waterfall curves that indicate population served by a given level of link availability for respective ones of the first and second orbital positions, the population weighted average availability for respective ones of the first and second orbital positions being a first selected availability requirement and a second selected availability requirement, respectively; (3) determining if the performance value set for at least one of the plurality of reference locations does not achieve one of a selected range, a selected maximum value or a selected minimum value; (4) if the performance value does not achieve one of a selected range, a selected maximum value or a selected minimum value, then selecting a different performance value; (5) if the performance value does achieve one of a selected range, a selected maximum value or a selected minimum value, then determining if the availability for the at least one of the plurality of reference locations meets the first selected availability requirement for the first orbital position, and meets the second selected availability requirement for the second orbital position; and (6) if the availability for the at least one of the plurality of reference locations fails to meet at least one of the first selected availability requirement and the second selected availability requirement, then selecting a different performance value for at least one of the plurality of reference locations.

[0013] In accordance with another aspect of the exemplary embodiments of the present invention, the first and second satellites have been optimized to each have a selected availability to achieve a selected performance value in the selected geographic coverage area. Determining the performance value for each of the plurality of reference locations comprises determining the maximum of the two performance values selected for the jointly optimized first satellite and the second satellite and at least initially setting the performance value of the universal antenna to the maximum performance value.

[0014] In accordance with another aspect of the exemplary embodiments of the present invention, one of a selected range, a selected maximum value or a selected

minimum value is selected to achieve link margin sufficient to close a communication link at that one of the plurality of reference locations when the universal antenna is deployed on a satellite in the farthest one of the first and second orbital positions.

[0015] In accordance with another aspect of the exemplary embodiments of the present invention, the performance value is based on power flux density required to achieve the selected link margin and availability at each of the plurality of locations in the selected geographic coverage area using the extended empirical roadside shadowing (EERS) model for defining a relationship between elevation angle and required margin.

[0016] In accordance with another aspect of the exemplary embodiments of the present invention, the method further comprises: (7) selecting different performance values for the universal antenna until predetermined criteria are met, the predetermined criteria comprising the performance value set for the universal antenna at each of the plurality of locations achieves one of a selected range, a selected maximum value or a selected minimum value, the availability for the universal antenna meets the first selected availability requirement and the second selected availability requirement for a selected number of the plurality of locations; (8) storing the selected different performance values for the universal antenna as the power requirements for the universal antenna; and (9) employing the determined power requirements to configure the universal antenna.

Brief Descriptions of the Drawings

[0017] The above and other aspects, features, and advantages of certain embodiments of the present invention will be more apparent from the following description taken in conjunction with the accompanying drawings, in which:

[0018] Fig. 1 illustrates the predicted baseline satellite system availability using conventional, jointly optimized transmit antenna patterns of two satellites in a conventional multiple satellite system;

[0019] Fig. 2 illustrates the predicted satellite system availability using an optimized antenna per Fig. 1 with a universal antenna configured in accordance with an embodiment of the present invention;

[0020] FIGS. 3 and 4 show, respectively, the elevation angles for two satellites positioned at 115° West and 85° West in an illustrative conventional multiple satellite system;

[0021] FIG. 5 is a graph depicting the conventional extended empirical roadside shadowing (EERS) model relationship between elevation angle and required margin for several levels of availability;

[0022] FIG. 6 is a schematic diagram of known sample locations in the contiguous United States;

[0023] FIG. 7 is a flow chart of a conventional implementation for jointly optimizing the transmit antenna patterns of two satellites in a conventional multiple satellite system;

[0024] FIG. 8 is a graph illustrating the predicted EERS availability for two satellites in a conventional illustrative multiple satellite system;

[0025] FIG. 9 depicts the achieved link margin for two satellites in a conventional illustrative multiple satellite system at various locations across the United States, corresponding to the predicted EERS availability of FIG. 8;

[0026] FIGS. 10 and 11 show the respective power flux density for the two satellites positioned at 115° West and 85° West in the illustrative conventional multiple satellite system;

[0027] FIGS. 12 and 13 show, respectively, the predicted single satellite EERS availability for the two satellites positioned at 115° West and 85° West in the illustrative conventional multiple satellite system;

[0028] FIG. 14 shows the predicted combined availability for a two-satellite system for the two satellites positioned at 115° West and 85° West in the illustrative conventional multiple satellite system;

[0029] FIG. 15 depicts a simplified example of the process of Fig. 7 for a single location and two satellites in the illustrative conventional multiple satellite system;

[0030] Fig. 16 is a flow chart of a series of operations for optimizing a universal antenna in accordance with an exemplary embodiment of the present invention; and

[0031] Fig. 17 is a matrix of data representing performance values achieved at each of a plurality of locations that is modified on a cell-by-cell basis to configure the requirements of a universal antenna based on a population-weighted metric in accordance with an exemplary embodiment of the present invention;

[0032] Figs. 18 and 19 are, respectively, a graph and corresponding table, in accordance with an exemplary embodiment of the present invention, that provide availability versus population data for each of a baseline configuration involving two satellites with jointly optimized antennas for their respective orbital positions, a spare satellite in a first orbital position with antenna jointly optimized for a different (e.g., second) orbital position in a multiple satellite system, and a spare satellite in the second orbital position with antenna jointly optimized for the first orbital position in the multiple satellite system; and

[0033] Figs. 20 and 21 are, respectively, a graph and corresponding table, in accordance with an exemplary embodiment of the present invention, that provide availability versus population data for each of a baseline configuration involving two satellites with jointly optimized antennas for their respective orbital positions, a spare satellite with universal antenna designed in accordance with an embodiment of the present invention and deployed to replace a satellite at a first orbital position in a multiple satellite system, and another spare satellite with universal antenna deployed to replace a satellite at a second orbital position in the multiple satellite system.

[0034] Throughout the drawings, the same drawing reference numerals will be understood to refer to the same elements, features, and structures.

Detailed Description Of The Exemplary Embodiments

[0035] In accordance with exemplary embodiments of the present invention, a system is provided for designing and configuring a transmit antenna, hereinafter referred to as a universal antenna, prior to deployment on a spare satellite that can replace any one satellite from all the satellites in a multiple satellite system. In accordance with an exemplary illustrated embodiment, the multiple satellite system is a broadcasting system that employs spatial diversity using at least two satellites positioned at 85° and 115° West longitude, respectively, to cover the contiguous United States with a selected degree of availability. It is to be understood that the universal antenna configured in accordance with the exemplary embodiments of the present invention can be used as a spare satellite in other types of multiple satellite systems besides a satellite radio broadcasting system such as a mobile communications satellite system or satellite systems that can provide position determination (e.g., Global Positioning System (GPS)) or paging services.

[0036] The universal antenna configured in accordance with exemplary embodiments of the present invention can produce a near-equal effective-isotropic-radiated-power (EIRP) pattern, independent of the orbital location in which the satellite is positioned, particularly when employed on a replacement satellite for a geostationary satellite. In a multiple satellite system (e.g., a satellite broadcast system employing spatial diversity with two satellites positioned at 85° West and 115° West), the universal antenna operates as a cost-effective in-orbit or ground spare satellite since the universal antenna can be positioned at either satellite location, thereby saving in capital investment and in time to construct the spare satellite. Predicted combined availability due to the spare satellite and one satellite having an optimized antenna is comparable to that achieved when optimized antennas are employed in both satellites for use in respective orbital locations, as described below in connection with Figs. 20 and 21. For example, calculated availability of the afore-mentioned existing satellite system (i.e., the satellite broadcast system employing spatial diversity with two satellites positioned at 85° West and 115° West) is shown in Fig. 1. The predicted satellite system availability with one of the two satellites being replaced

by the universal antenna is shown in Fig. 2. With reference to Fig. 2, the system availability when the universal antenna is used as a spare is reduced by less than 1.0% within the contiguous United States (CONUS). The respective shaded areas represent the changes in percentage availability, that is, a 0% to 1% positive change; a 0% to 1% negative change, and a 1% to 2% negative change, respectively.

[0037] FIGS. 3 and 4 show, respectively, the elevation angles for satellites located at 115° and 85° West longitude, respectively. From these figures, it is apparent that radio receivers in different regions of the United States will have differing line of sight (LOS) elevation angles to each of the two satellites. As a result, and in view of fading due to foliage, for example, different standing link margins are required to maintain a predetermined level of availability.

[0038] Exemplary embodiments of the present invention employ the Extended Empirical Roadside Shadowing (EERS) model available from the *Handbook of Propagation Effects for Vehicular and Personal Mobile Satellite Systems*, NASA Reference Publication 1274, 2nd ed., 11 Dec 1998 by Julius Goldhirsh and Wolfhard Vogel, which is incorporated herein by reference, to calculate the satellite link availability. It is to be understood that other models, studies, empirical data can be used to establish satellite link availability for satellite transmit analysis and optimization in accordance with exemplary embodiments of the present invention.

[0039] FIG. 5 is a graph depicting the EERS model relationship between elevation angle and required margin. The EERS model provides estimates of cumulative fade distributions due to roadside trees (i.e., foliage) within the following parameters: UHF (870 MHz) through S-Band (3 GHz), elevation angles to the satellite from 20° to 60° and percentages of outage from 1% to 20%. This well-known model is recommended by the International Telecommunications Union Radio Communication Section (ITU-R) (1994). Based on this model, it is possible to calculate a required link margin with respect to an elevation angle for desired levels of availability. These relationships are shown in the graph of FIG. 5. Thus, for example, in order to attain a 99% availability, it is necessary to have a link margin of approximately 33 dB where there is a 20° elevation angle to the satellite.

[0040] In a satellite radio broadcast system, which can potentially transmit to the entire CONUS, it is typically desirable to ensure that the relatively larger listening markets, i.e., populous cities and other more densely populated regions, have the highest possible reception availability, even at the expense of less populated regions. FIG. 6 is a schematic diagram of sample locations in the United States at which the EERS model was applied. Using this model, it is possible to determine the required transmit power flux density (PFD) to achieve the desired link margin and availability at each of the pre-selected regions, locations or points.

[0041] In accordance with U.S. Patent No. 6,470,058 describing the jointly optimized transmit antennas, in regions where one satellite's antenna could not achieve the desired power level in a particular location, that satellite's power requirement was reduced and the other satellite's transmit PFD was increased simultaneously for that location. The combined availability for both (or more) satellites met a desired level of availability for that location.

[0042] In accordance with exemplary embodiments of the present invention, the power requirement for the universal antenna at a location is set to meet selected criterion such as (1) to be within a selected range of performance values (e.g., EIRP), as well as (2) to achieve a desired availability based on respective curves representing population versus availability for satellites at each of at least two elevation angles that is less than an optimal baseline curve, as described below in connection with FIGS. 16-18. Where it is not possible to meet availability at each elevation angle for a point or location, the transmit PFD for the universal antenna can be redistributed from the transmit PFD or performance values (e.g., EIRP) among other locations having lower population and/or lower intrinsic fading probability. The process of meeting these criteria for all or a selected ratio of the representative locations is, for example, iterative and repeated until an acceptable universal antenna pattern solution is found that satisfies each satellite. Of course, other criterion for choosing locations which might have to be allocated reduced availability is also within the scope of the present invention.

[0043] Before describing configuring a universal antenna to replace one of plural jointly optimized antennas in accordance with exemplary embodiments of the present invention, the optimization of the conventional jointly optimized antennas will be first described in connection with FIGS. 7-15. As shown in FIG. 7, at step 502, an objective model that can predict link margins based on elevation angles, power, foliage (fading), etc., is chosen. The EERS model was chosen since it is one of the more well-accepted predictive modeling standards by those skilled in the art. Then, at step 504, the initial required transmit PFD of each satellite at a number of locations within the desired coverage area (e.g., those shown in FIG. 5) is determined based on the desired margin to achieve a given availability.

[0044] The availability goal for a single satellite is preferably given by

[0045] $Av_{SAT1} = 1 - \text{square root}(1 - Av_{BOTH})$

[0046] This formula applies only for two satellites where the outages of one are statistically independent of the other. Other formulas to determine the individual satellite availability when a goal for both (or all in the case of more than two satellites) may also be used provided that a mathematical relationship of some kind can be assumed between the individual availability and the joint or combined availability for the group of satellites.

[0047] For example, if the availability goal for both satellites is 99%, then the single satellite availability Av_{SAT1} goal would be 90%. If the availability of the two satellites was somehow statistically related rather than being independent, a goal of higher than 90% for each satellite would be required to achieve 99% joint availability.

[0048] The Margin (M) required to achieve the desired availability (Av) can be determined using the EERS model as a function of elevation angle (θ), using the following formula:

[0049] $M(Av, \theta.fL)) = \alpha(Av) + \beta(Av)\theta + \gamma(Av)\theta^2$

[0050] If all regions have attained sufficient power levels to achieve the desired margin (and thus availability), that is, if at step 506 the PFD and desired joint availability is attainable and/or acceptable at each location, then the process for jointly optimizing antennas ends and the antennas are deemed to be optimized in accordance with the desired goals, e.g., 99% availability. However, in regions where one satellite's antenna cannot achieve the desired power level, or cannot achieve an acceptable power level, the process continues with step 508 at which it is determined if all possible PFD requirement combinations have been tested or analyzed. If not, the process continues with step 510 where the power requirement for the incapable satellite's antenna is reduced. Immediately thereafter, at step 512, the PFD requirement is increased for the antenna on the other satellite for the same location. The process then returns to step 506 to determine whether the combined availability for both satellites meets the desired availability, e.g. 99%.

[0051] As shown in FIG. 7, the process for jointly optimizing antennas continues until it is no longer feasible to decrease or increase the required PFD on a given satellite and make the opposite adjustment on the other satellite. More specifically, at step 508, it is determined whether there are any remaining combinations of required PFD for a given location to analyze. If all possible combinations, or more precisely, if a substantial or reasonable subset of all possible combinations has been analyzed without realizing a satisfactory antenna pattern solution, then the process continues with step 514 where the PFD requirement is decreased for both satellites at the location being analyzed. Reduction of the PFD requirement for both satellites is preferably reserved for locations that are less populated, have relatively less susceptibility to fading due to foliage and/or are deemed to be commercially less important and thus can be sacrificed in order to provide better availability to other location or regions.

[0052] FIG. 8 is a graph illustrating the predicted EERS availability for two satellites. Uniform high availability can be achieved by matching over-performing regions (e.g., better than 90%) on one satellite with under-performing regions (e.g., below 90%) on the other satellite. FIG. 9 depicts the achieved link margin for two

satellites with jointly optimized antennas in accordance with FIG. 7 at various locations across the United States, corresponding to the predicted EERS availability of FIG. 6. FIGS. 10 and 11 show the respective power flux density of satellites at 115° and 85° West longitude. FIGS. 12 and 13 show, respectively, the predicted single satellite EERS availability for the two satellites. These figures, in combination with FIG. 14, which shows the predicted combined availability for a two-satellite system, clearly show the benefit of an iterative process for jointly optimized antennas per FIG. 7.

[0053] FIG. 15 depicts an exemplary iterative process for availability optimization for a two-satellite system with jointly optimized antennas per FIG. 7. As shown, if 90% availability is desired from both satellites, then, assuming a maximum EIRP limit of 66 dBW, the second satellite's EIRP is unrealizable. If the first satellites desired availability is increased to 95% and the second satellite's desired availability is decreased to 80%, then the first satellite's EIRP is unrealizable. Accordingly, the first satellite's desired availability is decreased slightly to 94% and the second satellite's desired availability is increased to 83%, whereby a realizable solution is achieved.

[0054] In accordance with exemplary embodiments of the present invention, one or more availability "waterfall" curves, each showing population (i.e., estimated population for a selected geographic area) served at a given level of link availability (e.g., %), are selected for use when configuring a universal antenna that can be deployed on a replacement satellite for either of two or more satellites in a multiple satellite system that have jointly optimized antennas (e.g., per FIG. 7). Fig. 20 depicts a baseline availability curve showing availability (%) relative to population for a satellite employing two jointly optimized antennas. Ideally, 100 % availability is achieved for 100 % of the population for the area served by the satellite constellation (e.g., the contiguous United States served by the two spatially diverse satellites in the illustrated embodiments). For a realistically achievable availability curve, a satellite is configured to provide, for example, approximately 99% availability to 95% of the population. It is desirable to maximize the area under the availability curve. As will be described in more detail below in connection with Fig. 16, an iterative process of

allocating system resources (e.g., performance, link margin) among a selected number of representative points in the intended geographic coverage or service area in accordance with an exemplary embodiment of the present invention seeks to maximize the area under the selected availability waterfall curve (e.g., Fig. 20).

[0055] In the illustrated and exemplary embodiment of the present invention, at least one maximum availability waterfall graph such as Fig. 20 is used for designing the universal antenna regardless of the orbital position to which the replacement satellite having the universal antenna is deployed. Fig. 20 also depicts respective curves showing population versus availability depending on the orbital position to which the replacement satellite having the universal antenna is deployed. For example, FIG. 20 provides two other curves besides the baseline curve for a replacement satellite with universal antenna being deployed at respective ones of the satellites at 115° and 85° West longitude and indicated at Universal SAT A and Universal SAT B. With reference to FIG. 21, a population weighted average availability is determined for each of the three curves depicted in FIG. 20. FIGs. 18 and 19 provide population versus availability data for the baseline and two other configurations (i.e., a baseline configuration involving two satellites with jointly optimized antennas for their respective orbital positions in a multiple satellite system, a spare satellite in a first orbital position with antenna jointly optimized for a different (e.g., second) orbital position in the multiple satellite system, and a spare satellite in the second orbital position with antenna jointly optimized for the first orbital position in the multiple satellite system). By comparing FIGs. 20 and 21 with FIGs. 18 and 19, it can be seen that system availability when the universal antenna is used on a spare satellite, as opposed to one of the jointly optimized antennas, is reduced by less than 1.0% as stated above.

[0056] With reference to step 1602 in FIG. 16, a method for configuring a universal antenna in accordance with an exemplary embodiment of the present invention preferably commences with selecting an objective model that can predict link margins based on elevation angles, power, foliage (fading), and so on. The EERS model is preferably used since it is one of the more well-accepted predictive modeling

standards by those skilled in the art. Then, at step 1604, the initial required transmit PFD of each satellite at a number of locations within the desired coverage area is determined based on the desired margin to achieve a given availability determined via the EERS model. For example, the initial transmit PFD can be the transmit PFD of each satellite having a jointly optimized antenna determined via the iterative process shown in FIG. 7.

[0057] A subset of representative latitude and longitude points (e.g., N geographic points or locations where N is a selected integer number) such as N of the sample locations depicted in Fig. 6 are preferably selected for determining if selected performance and availability criteria are met to configure the universal antenna in accordance with FIG. 16. The sample locations are reference points within the CONUS in the illustrated example and are each characterized by certain attributes such as population, elevation angles to satellites in each of the orbital positions, and relative importance. Relative importance of the reference points is not necessarily based on population but can be based on desired customer base in the region surrounding the sample location, or desired continuity of coverage within that region relative to adjacent regions, and so on.

[0058] With reference to Fig. 17, a matrix of data relating to these N reference points is preferably created for determining, storing and updating data (e.g., data relating to system resources allocated among the N points) during the iterative process of FIG. 16 to design a universal antenna that can be used on a replacement satellite in any of two or more orbital positions in a multiple satellite system. The data for the universal antenna preferably comprises at least performance data (e.g., EIRP) determined using the iterative process illustrated in FIG. 16. The matrix can comprise additional data as well, such as population census data, relative importance and the like for each of the N sample locations or reference locations.

[0059] With continued reference to FIG. 16, for each of the N selected sample locations or reference points, the performance (e.g., link margin expressed as EIRP) for the satellite having a universal antenna is initially set at the larger of the performance data for each of the satellites having a jointly optimized antenna (step

1606) such as that determined in accordance with FIG. 7. As indicated by steps, 1608, 1610, 1612 and 1614, an iterative process commences. First, it is determined whether the satellite with universal antenna can achieve the performance for a selected one of the locations (step 1608). The selected location can be the first of the N locations, that is, the first row in the matrix of FIG. 17, and the iterative process can continue on through to the following consecutive locations. Alternatively, the iterative process can commence using a location having the largest corresponding population or greatest relative importance, and the iterative process can continue through all or a subset of the remaining locations in the order of locations having the largest corresponding populations to the smallest populations or greatest relative importance to least relative importance.

[0060] With continued reference to step 1608 in FIG. 16, the performance value initially set for the satellite with universal antenna may be outside a selected range or beyond a selected maximum or minimum EIRP limit similar to the EIRP limit used above in connection with FIG. 15. Alternatively, the performance value can be determined to be insufficient to close on communication, that is, the link margin selected for the universal antenna can be insufficient to close on the communication link needed at the geographic location for a replacement satellite in the farthest orbital position. For example, the performance can be deemed to not have been achieved if a selected link margin is not sufficient to overcome the potential (i.e., probabilistic) link degradation due to foliage, for example, as determined using the EERS model for a specific location's elevation angle and PFD at that location. Thus, some reference points may require allocation of as much as 10-12 dB margin to achieve performance for that location based on elevation angle and optionally other selected factors such as relative importance with respect to other reference points. Performance or system resources are allocated among the selected reference points in the matrix to achieve availability for preferably all orbital positions or elevation angles where a satellite with universal antenna may be deployed. For a first reference point where performance or link margin is met, the iterative process of FIG. 16 can borrow resources allocated to this first point for allocation to another reference point,

where performance and/or availability is not yet achieved, based on selected criteria such as relative importance without degrading the performance of the first reference point to an unacceptable level. Thus, performance can be increased for other reference points were margin was previously deemed too low in step 1608. Further, some points may be considered to be of such little relative importance as to permit failure to achieve a selected performance at that location per step 1608 if other reference points of greater importance require those resources.

[0061] If the performance value set for the satellite with universal antenna (e.g., initially per step 1606 or via a prior iteration of step 1614) is realizable (e.g., can be achieved with sufficient link margin to close the communication link while taking selected losses and errors into consideration), then it is determined whether the waterfall curves (e.g., the two non-baseline curves in FIG. 20 and non-baseline entries in FIG. 21) for both of the Universal SAT A and Universal SAT B are satisfied (steps 1610 and 1612). For example, reference points characterized by lack of elevation angle relative to a satellite can be allocated more power to achieve a desired availability such as that provided in Figs. 20 and 21. Two or more curves are preferably used since the different elevation angles of the potential two or more replacement satellite orbital positions can create different availability for a selected geographic location, in which case the satellite resources (e.g., PFD) need to be retasked or redistributed to optimally accommodate the populations of the different geographic locations. In other words, if the performance value set for the satellite with universal antenna is not realizable, or either of the waterfall curves for the Universal SAT A and Universal SAT B are not satisfied, then the performance value(s) are redistributed among the other locations or stations per (step 1614) preferably using a population-weighted metric or other metric such as relative importance. As stated above, the performance (e.g., EIRP) for the satellite with universal antenna can be increased or decreased for another location(s) or reference point(s), depending on its corresponding population or relative importance, to achieve the above-referenced criteria in steps 1608, 1610 and 1612, that is, that the

performance value set for the satellite with universal antenna is realizable, and both of the waterfall curves for the Universal SAT A and Universal SAT B are satisfied.

[0062] Once the criteria in steps 1608, 1610 and 1612 are met, the data for the satellite with universal antenna at the next location can be reviewed and changed per step 1614 until the universal satellite antenna data for last location in the matrix is analyzed and determined per step 1618. It is to be understood that the data for only a subset or selected ratio of the N sample locations needs to be determined to meet the criteria in steps 1608, 1610 and 1612. Further, the necessary criteria can be changed depending on the corresponding population (e.g., only a subset of the criteria needs to be met for locations in less densely populated areas) or relative importance, or additional different criteria can be imposed as the iterative process progresses.

[0063] In view of the foregoing, the present invention makes it possible to optimize a spare satellite antenna pattern to be used on a replacement satellite for any of the satellites in the space-based broadcasting segment of a multiple satellite system. The shape of the universal antenna can be implemented using known methods. It is noted that, once a desired antenna pattern is calculated, there are well-known methods to practically implement the optimized design on the actual satellite antenna. These methods or techniques can include, but are not limited to, physically shaping the antennas, orienting them, as well as programming phased array antennas to achieve the desired effective pattern.

[0064] The universal antenna can be, for example, an offset-fed reflector having a nominal circular aperture. The surface of the reflector is modified from its paraboloid shape such as to induce the appropriate current density and phasing. A secondary shaped beam is created to match a selected geographic such has the CONUS. The modified surface is expressed by a mathematical polynomial expression, of which all coefficients are continuously modified until a desired secondary beam is achieved, based for example on the universal antenna pattern developed using an iterative process as exemplified in FIG. 16. As stated above, extensive analytical analyses, using methods described herein, demonstrate that the combined satellite availability, with one satellite using a universal antenna and one

satellite uses a jointly optimized antenna, both as described herein with reference to FIGS. 16 and 7, respectively, does not degrade significantly.

[0065] The present invention is preferably implemented with software that is run on a general purpose computer. Of course, portions, or even all of the functionality described herein could also be implemented directly in electronic hardware. The software can also be embodied as computer-readable codes on a computer-readable recording medium. The computer-readable recording medium is any data storage device that can store data which can thereafter be read by a computer system. Examples of the computer-readable recording medium include, but are not limited to, read-only memory (ROM), random-access memory (RAM), CD-ROMs, magnetic tapes, floppy disks, optical data storage devices, and carrier waves (such as data transmission through the Internet via wired or wireless transmission paths). The computer-readable recording medium can also be distributed over network-coupled computer systems so that the computer-readable code is stored and executed in a distributed fashion. Also, functional programs, codes, and code segments for accomplishing the present invention can be easily construed as within the scope of the invention by programmers skilled in the art to which the present invention pertains

[0066] Further, in describing representative embodiments of the present invention, the specification may have presented the method and/or process of the present invention as a particular sequence of steps. However, to the extent that the method or process does not rely on the particular order of steps set forth herein, the method or process should not be limited to the particular sequence of steps described. As one of ordinary skill in the art would appreciate, other sequences of steps may be possible. Therefore, the particular order of the steps set forth in the specification should not be construed as limitations on the claims. In addition, the claims directed to the method and/or process of the present invention should not be limited to the performance of their steps in the order written, and one skilled in the art can readily appreciate that the sequences may be varied and still remain within the spirit and scope of the present invention.

[0067] The foregoing disclosure of the exemplary embodiments of the present invention have been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many variations and modifications of the embodiments described herein will be obvious to one of ordinary skill in the art in light of the above disclosure. The scope of the invention is to be defined only by the claims appended hereto, and by their equivalents.

WHAT IS CLAIMED IS:

1. A method for optimizing an antenna pattern for a universal antenna to replace either of first and second antennas on respective ones of first and second satellites that have been deployed in first and second orbital positions and configured to operate in conjunction with each other to deliver signals to each of a plurality of receivers in a selected geographic coverage area having differing line of sight elevation angles to each of the first and second satellites, the method comprising:

determining, for each of a plurality of reference locations in the selected geographic coverage area, an initial performance value;

determining a population weighted average availability using first and second availability waterfall curves that indicate population served by a given level of link availability for respective ones of the first and second orbital positions, the population weighted average availability for respective ones of the first and second orbital positions being a first selected availability requirement and a second selected availability requirement, respectively;

determining if the performance value set for at least one of the plurality of reference locations does not achieve one of a selected range, a selected maximum value or a selected minimum value;

if the performance value does not achieve one of a selected range, a selected maximum value or a selected minimum value, then selecting a different performance value;

if the performance value does achieve one of a selected range, a selected maximum value or a selected minimum value, then determining if the availability for the at least one of the plurality of reference locations meets the first selected availability requirement for the first orbital position, and meets the second selected availability requirement for the second orbital position; and

if the availability for the at least one of the plurality of reference locations fails to meet at least one of the first selected availability requirement and the second

selected availability requirement, then selecting a different performance value for at least one of the plurality of reference locations.

2. A method as claimed in claim 1, wherein the first and second satellites having been optimized to each have a selected availability to achieve a selected performance value in the selected geographic coverage area, and determining the performance value for each of the plurality of reference locations comprises determining the maximum of the two performance values selected for the jointly optimized first satellite and the second satellite and at least initially setting the performance value of the universal antenna to the maximum performance value.

3. A method as claimed in claim 1, wherein one of a selected range, a selected maximum value or a selected minimum value is selected to achieve link margin sufficient to close a communication link at that one of the plurality of reference locations when the universal antenna is deployed on a satellite in the farthest one of the first and second orbital positions.

4. A method as claimed in claim 1, wherein the performance values of the plurality of reference locations are selected such that the universal antenna fails to meet at least one of the first selected availability requirement and the second selected availability requirement for a higher percentage of the plurality of reference locations that are in less densely populated parts of the selected geographic coverage area than the reference locations in more densely populated parts of the selected geographic coverage area.

5. A method as claimed in claim 1, further comprising assigning each of the plurality of reference locations a relative importance value indicating a relative importance rank, the relative importance corresponding to at least one of desired customer base in the region surrounding the reference location and desired continuity of coverage within that region relative to adjacent regions.

6. A method as claimed in claim 5, wherein the performance values of the plurality of reference locations are selected such that the universal antenna meets at least one of the first selected availability requirement and the second selected availability requirement for respective ones of the plurality of reference locations having a high relative importance rank.

7. A method as claimed in claim 1, wherein the performance value is based on effective isotropic radiated power (EIRP) in dBW.

8. A method as claimed in claim 1, wherein the performance value is based on power flux density required to achieve a selected link margin at a selected one of the plurality of locations in the selected geographic coverage area less selected losses and errors.

9. A method as claimed in claim 1, wherein the performance value is based on power flux density required to achieve the selected link margin and availability at each of the plurality of locations in the selected geographic coverage area using the extended empirical roadside shadowing (EERS) model for defining a relationship between elevation angle and required margin.

10. A method as claimed in claim 1, further comprising the steps of:

selecting different performance values for the universal antenna until predetermined criteria are met, the predetermined criteria comprising the performance value set for the universal antenna at each of the plurality of locations achieves one of a selected range, a selected maximum value or a selected minimum value, the availability for the universal antenna meets the first selected availability requirement and the second selected availability requirement for a selected number of the plurality of locations;

storing the selected different performance values for the universal antenna as the power requirements for the universal antenna; and

employing the determined power requirements to configure the universal antenna.

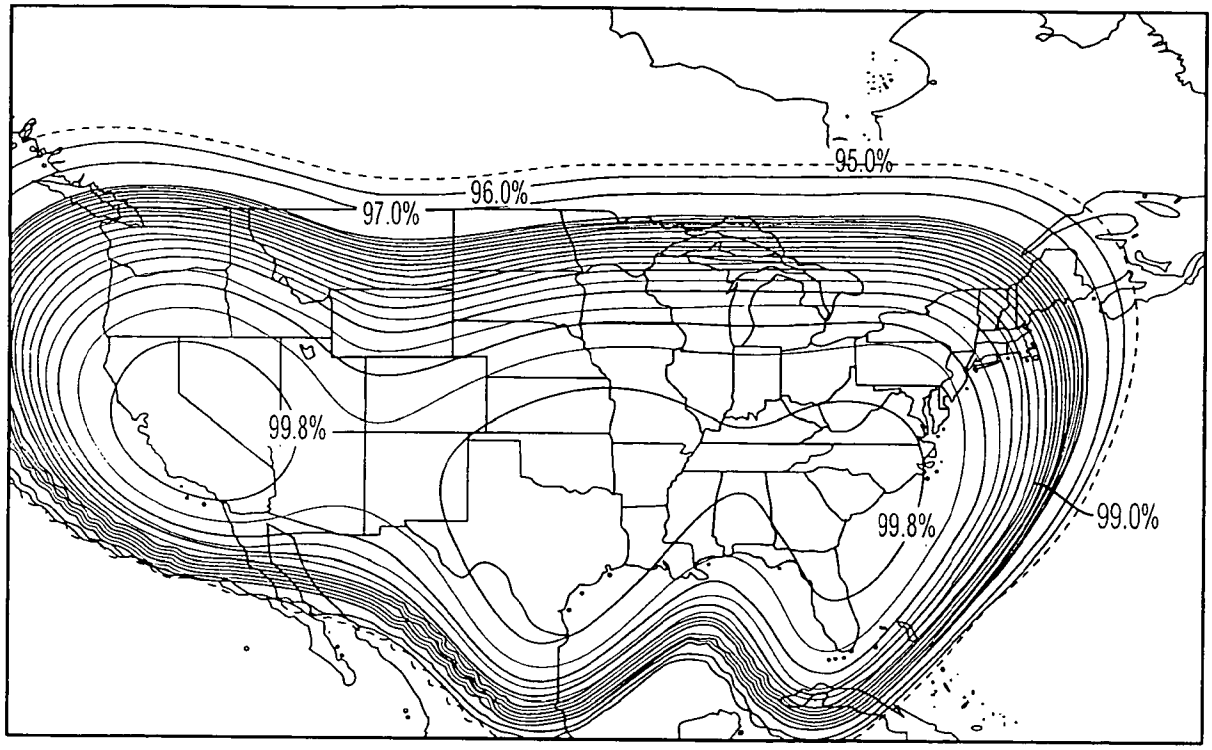

95.0%
96.0%
97.0%
99.8%
99.8%
99.0%

FIG. 1

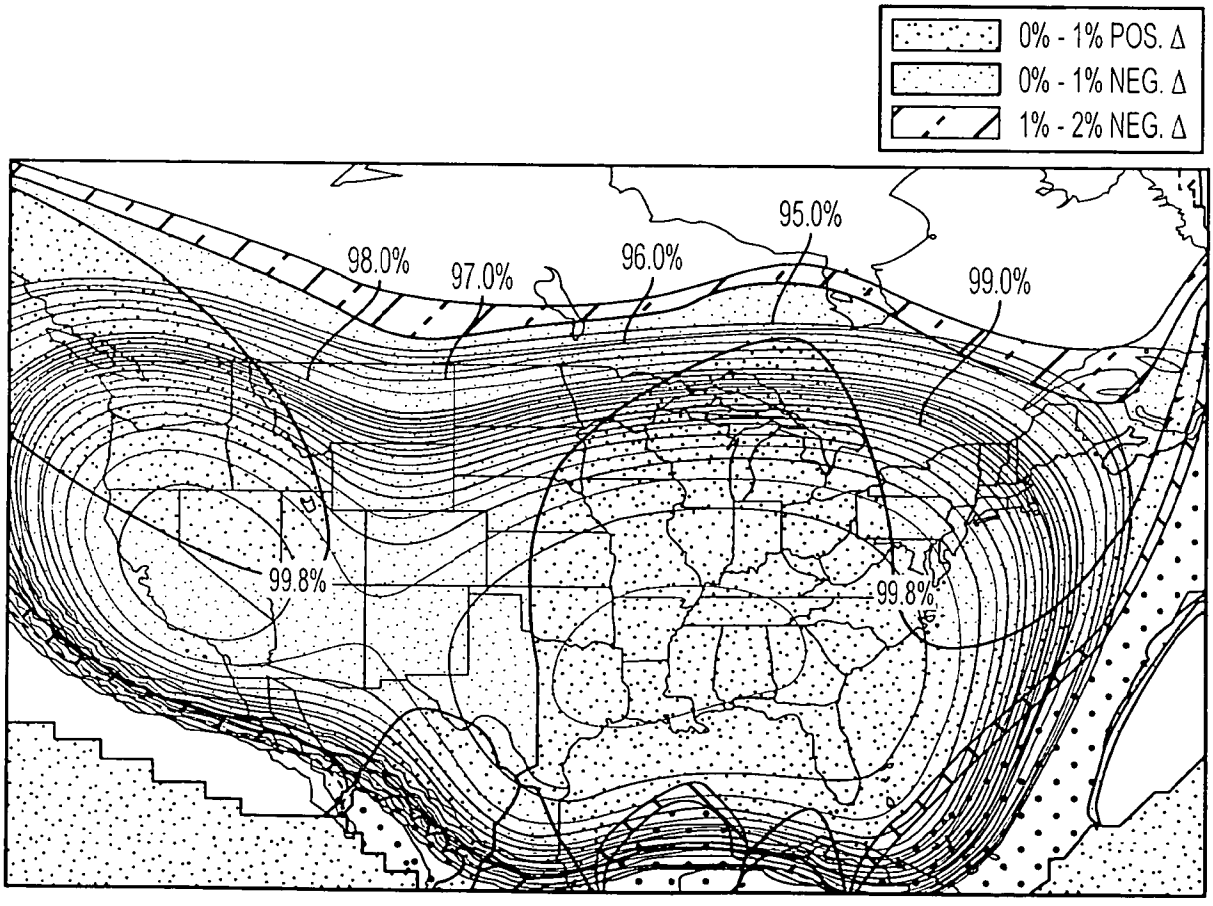

0% - 1% POS. Δ
0% - 1% NEG. Δ
1% - 2% NEG. Δ
95.0%
98.0%
97.0%
96.0%
99.0%
99.8%
99.8%

FIG. 2

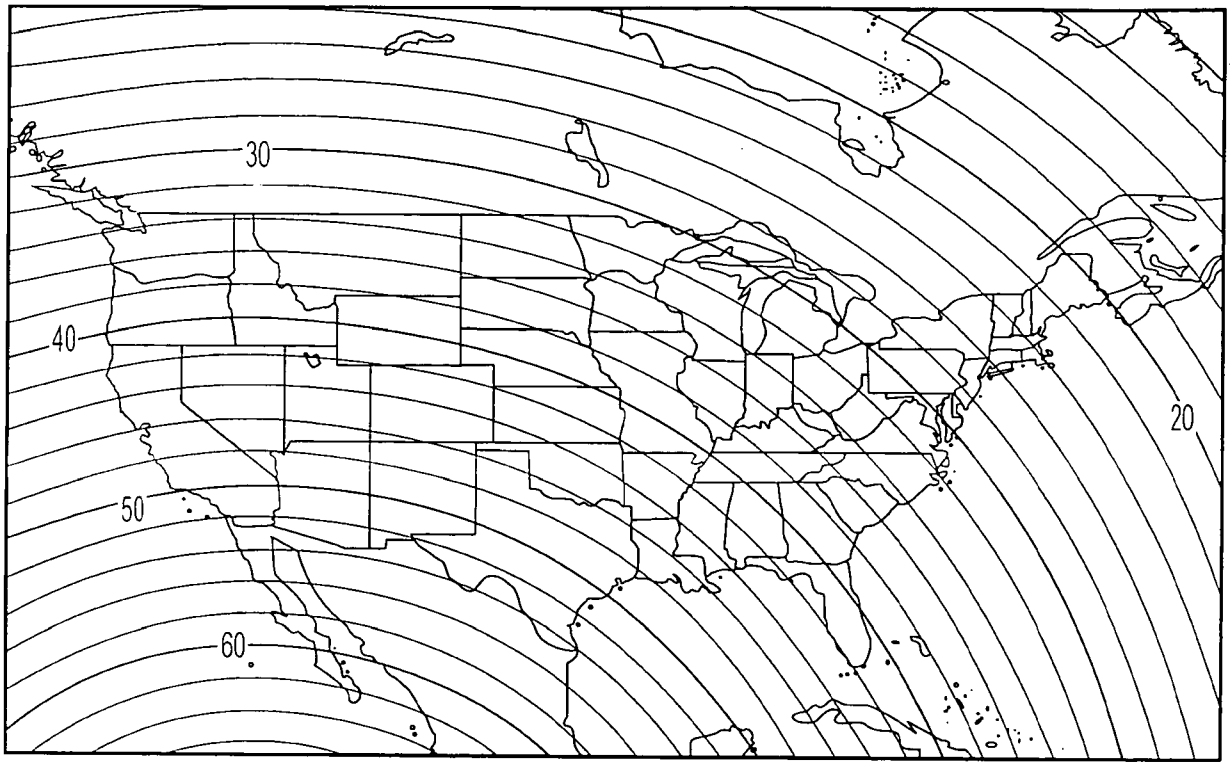


FIG. 3
PRIOR ART

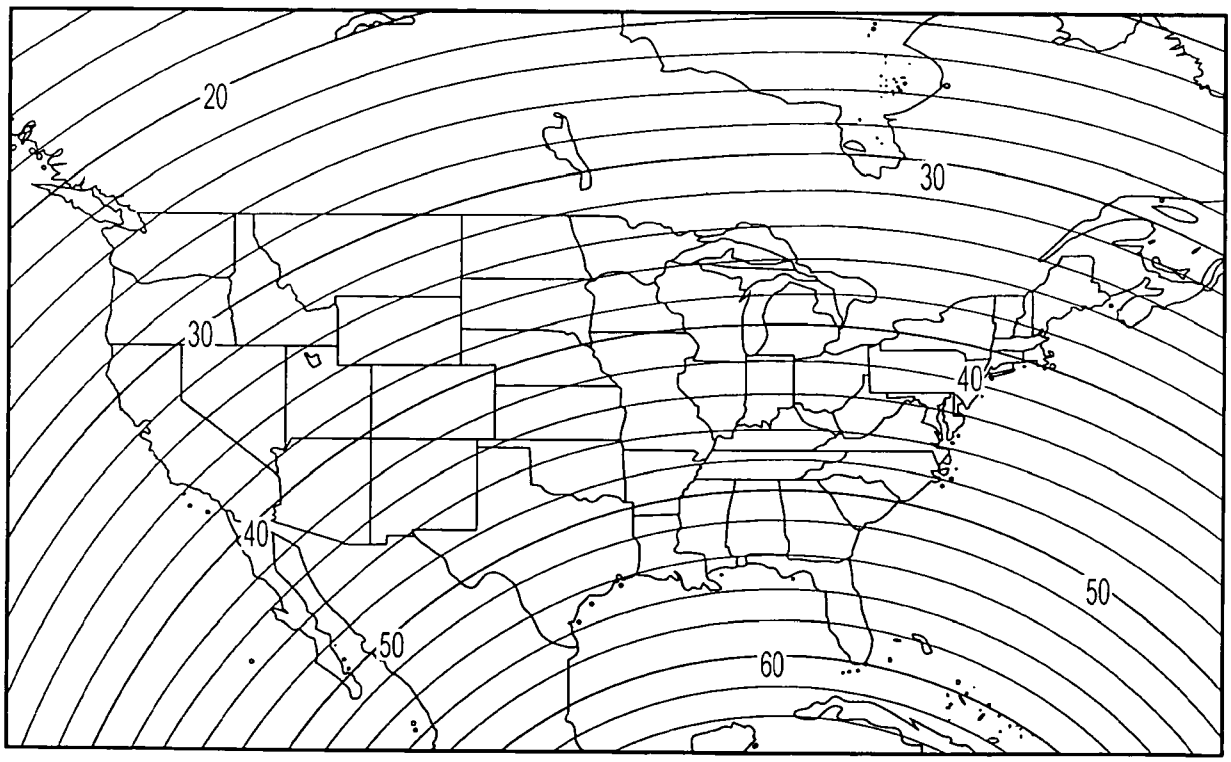


FIG. 4
PRIOR ART

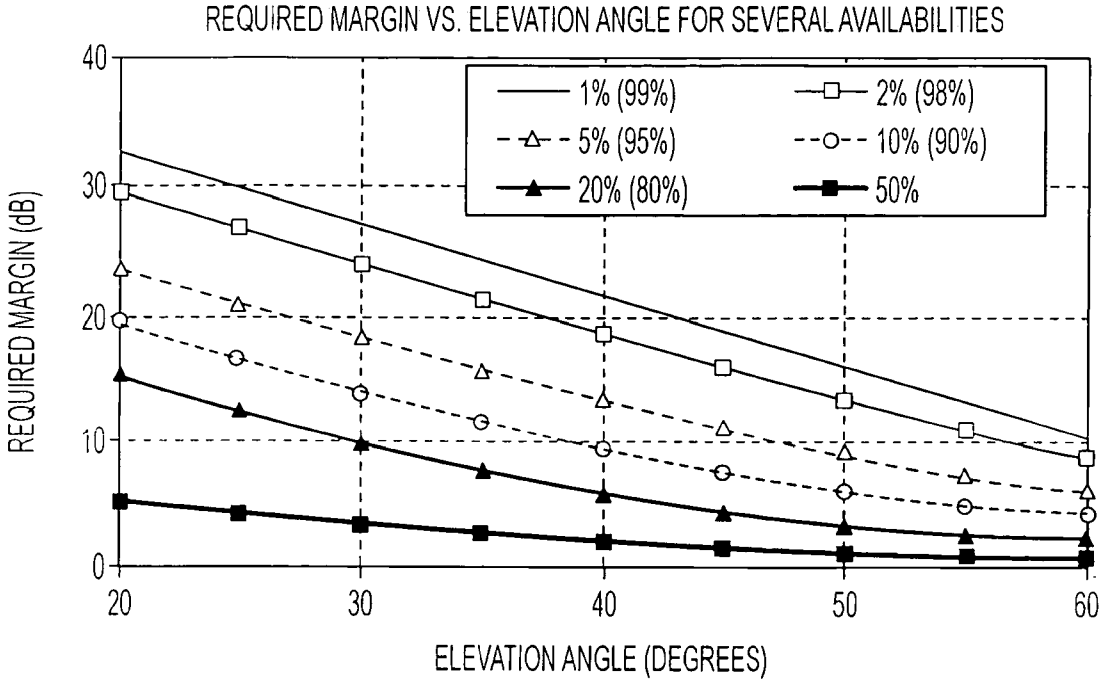


FIG. 5
PRIOR ART

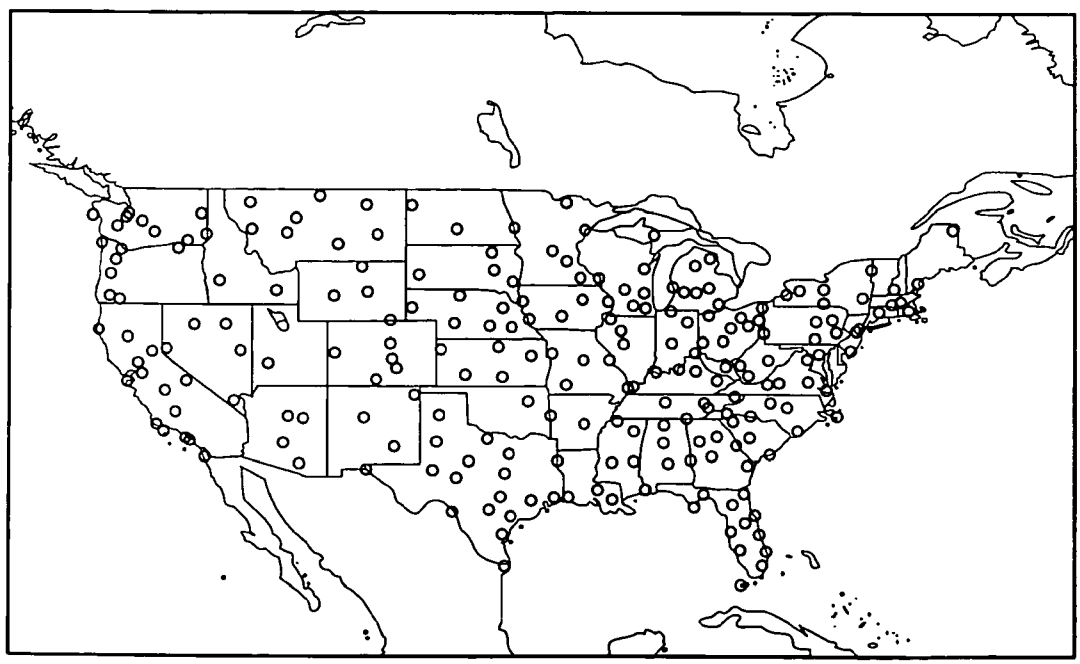


FIG. 6
PRIOR ART

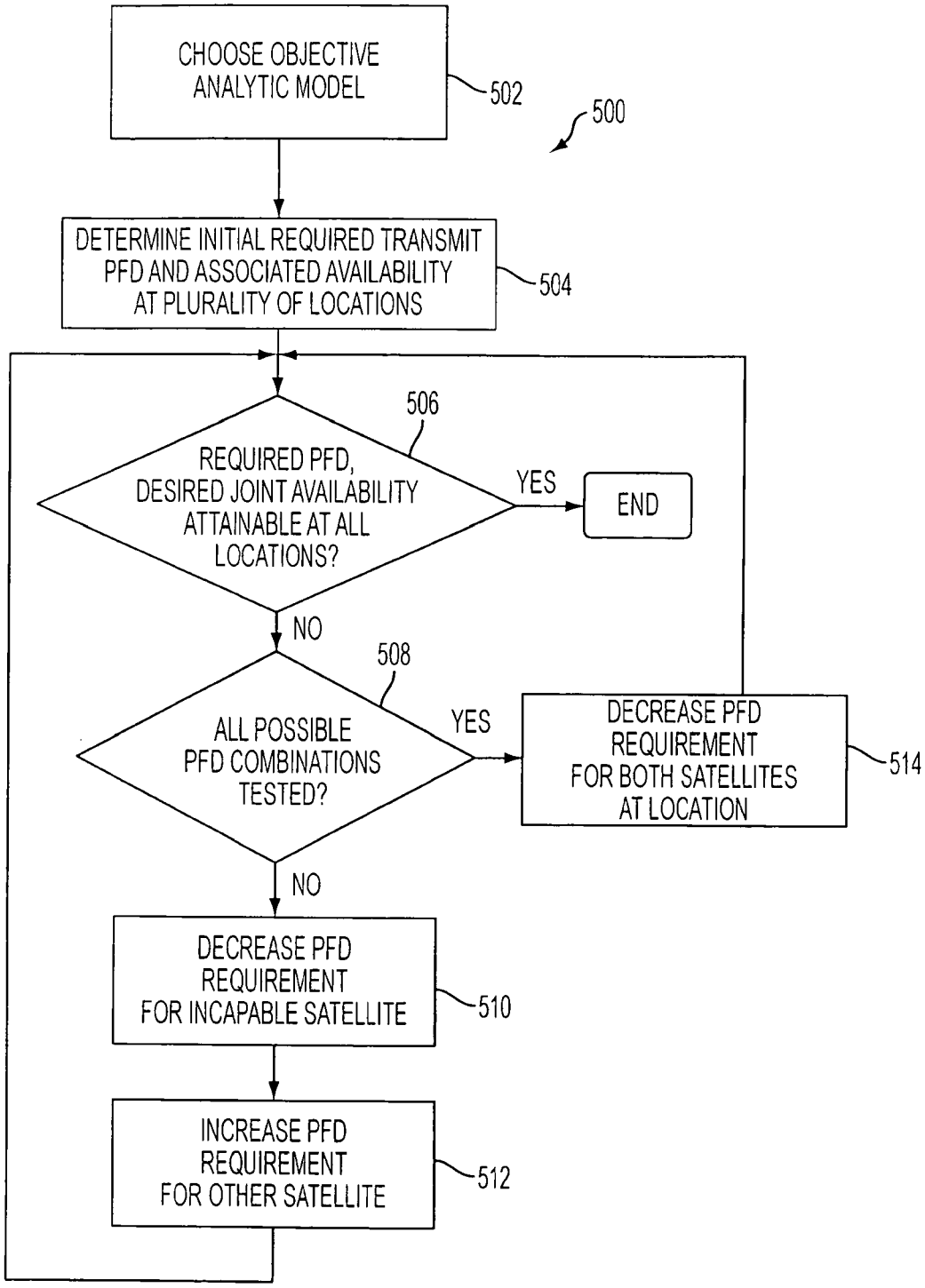


FIG. 7
PRIOR ART

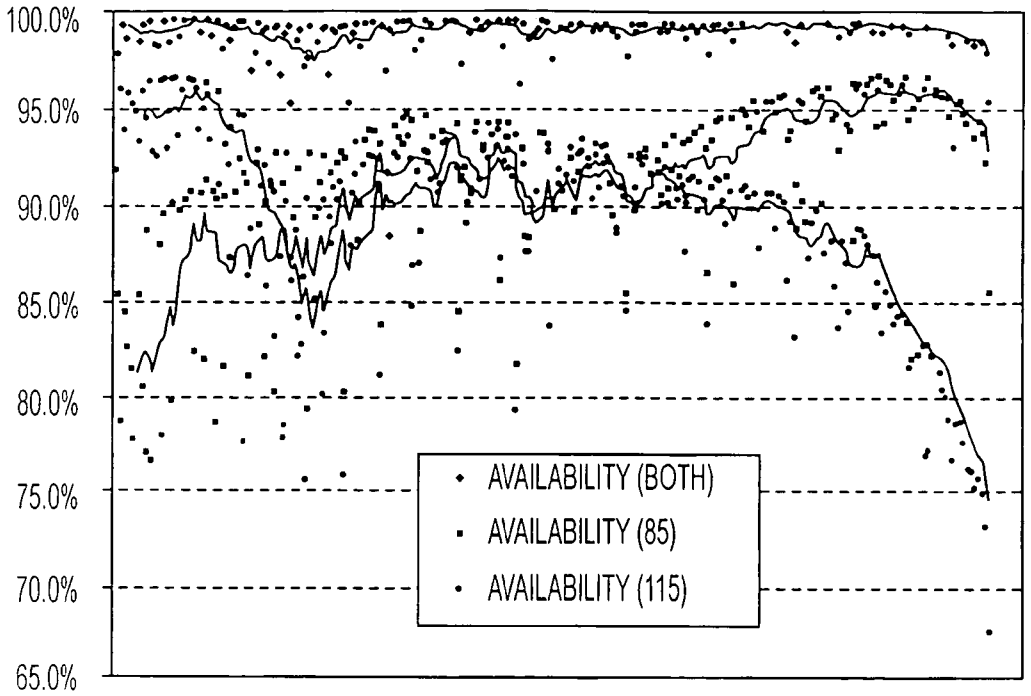


FIG. 8
PRIOR ART

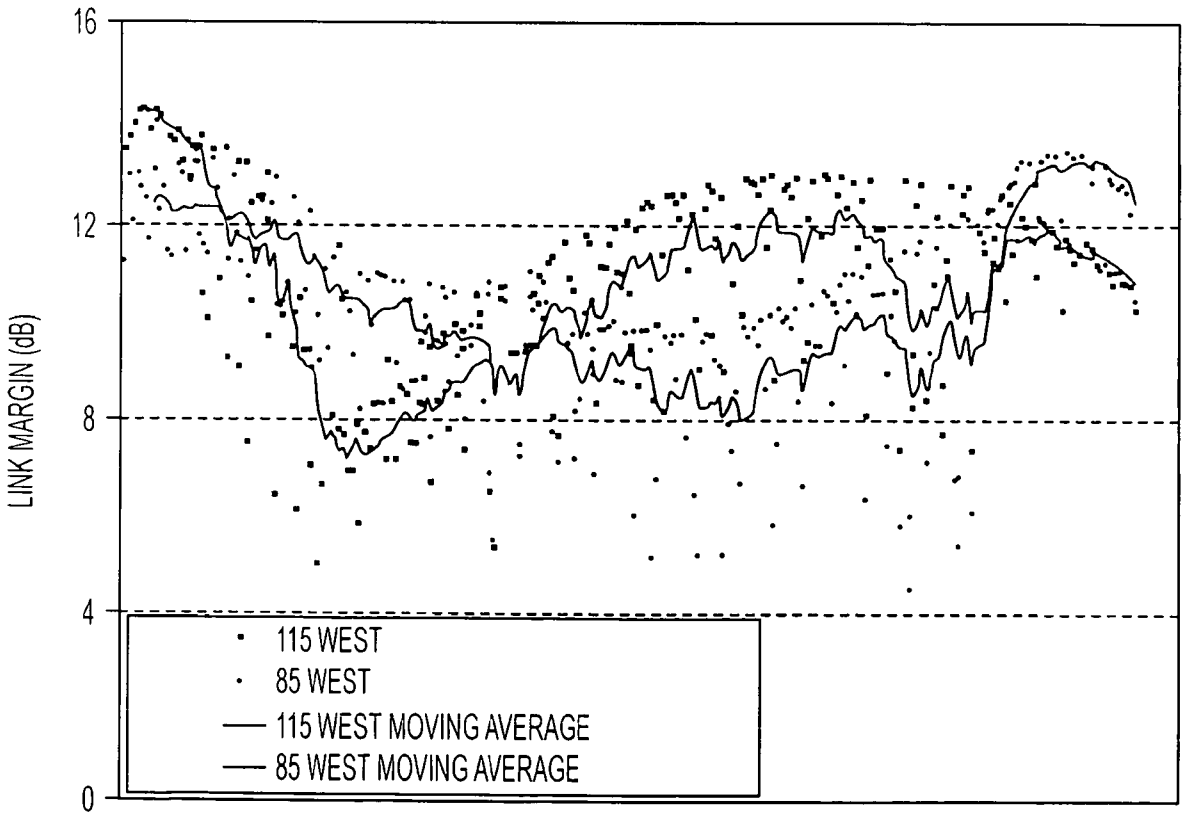


FIG. 9
PRIOR ART

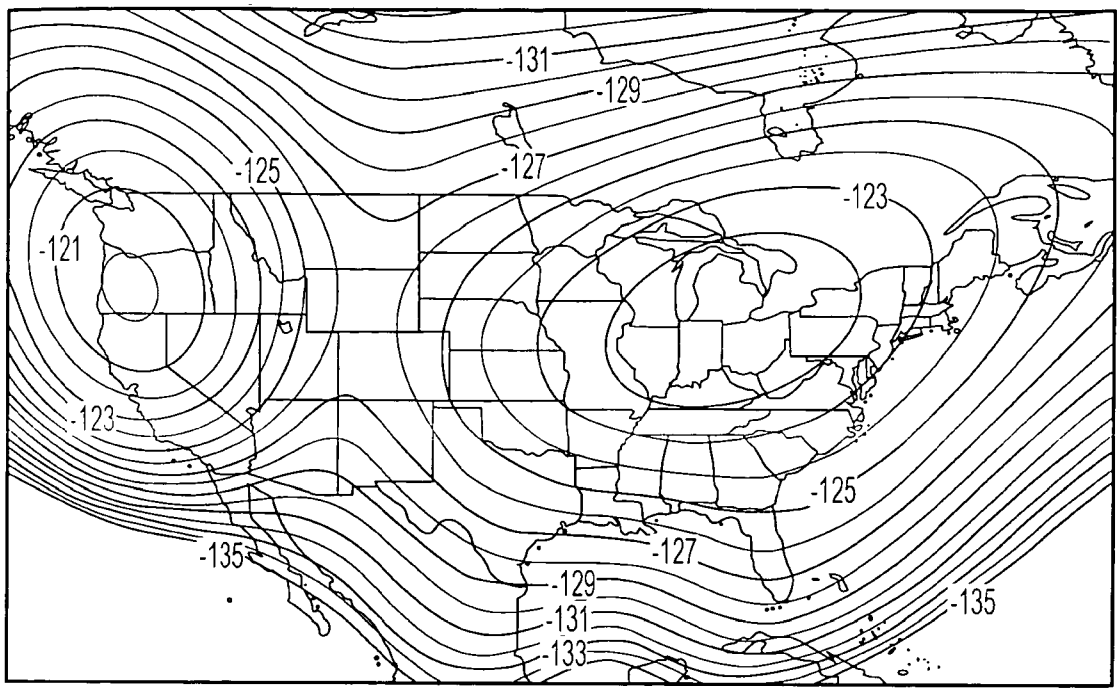


FIG. 10
PRIOR ART

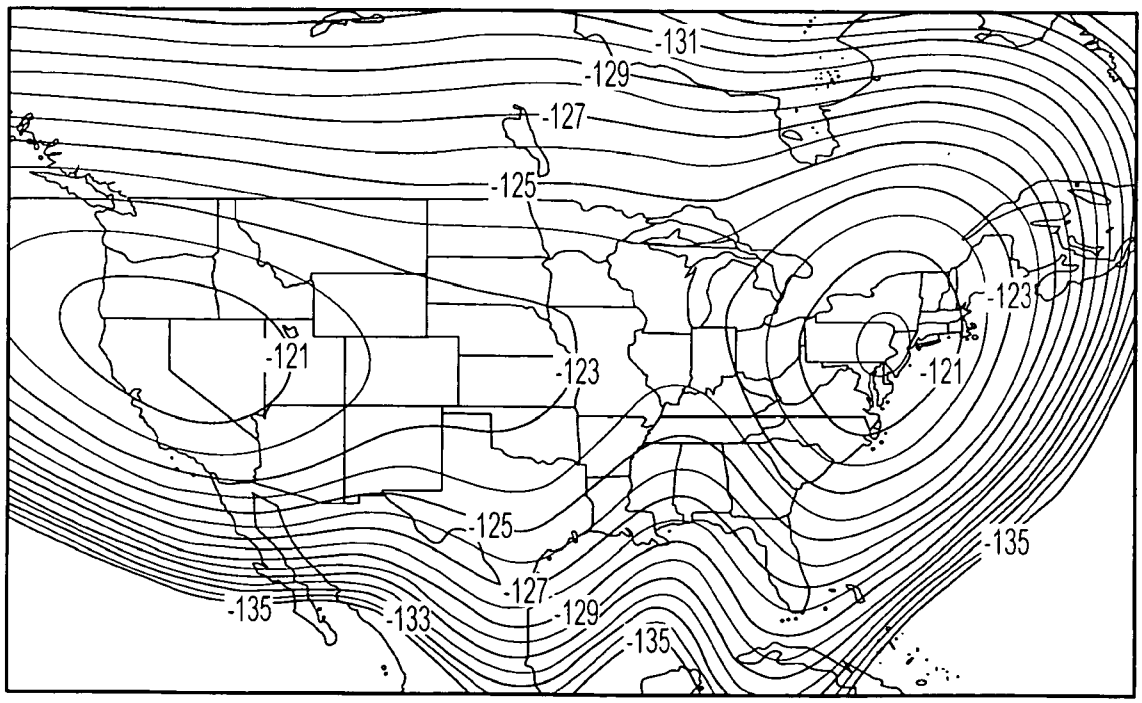


FIG. 11
PRIOR ART

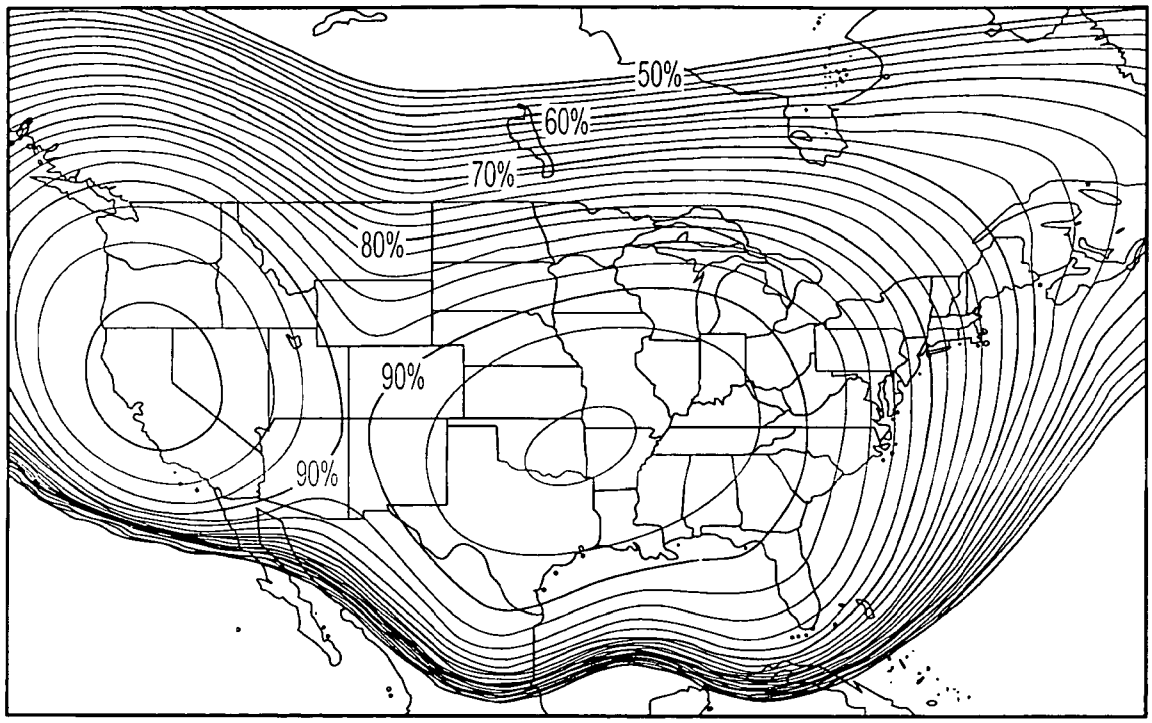


FIG. 12
PRIOR ART

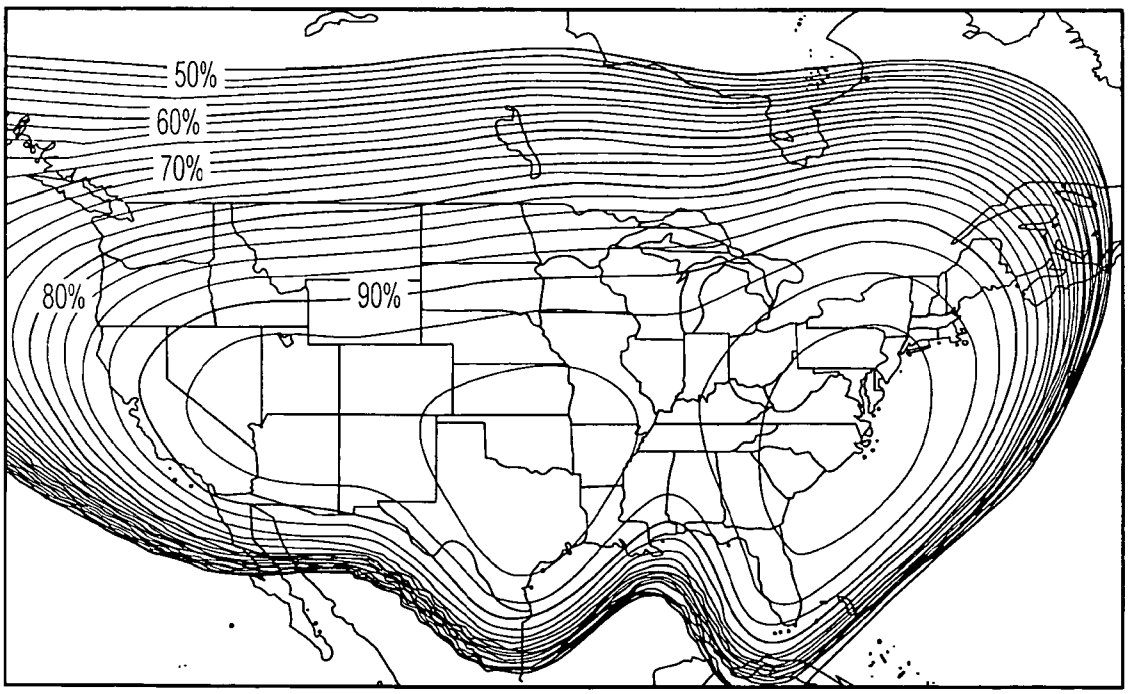


FIG. 13
PRIOR ART

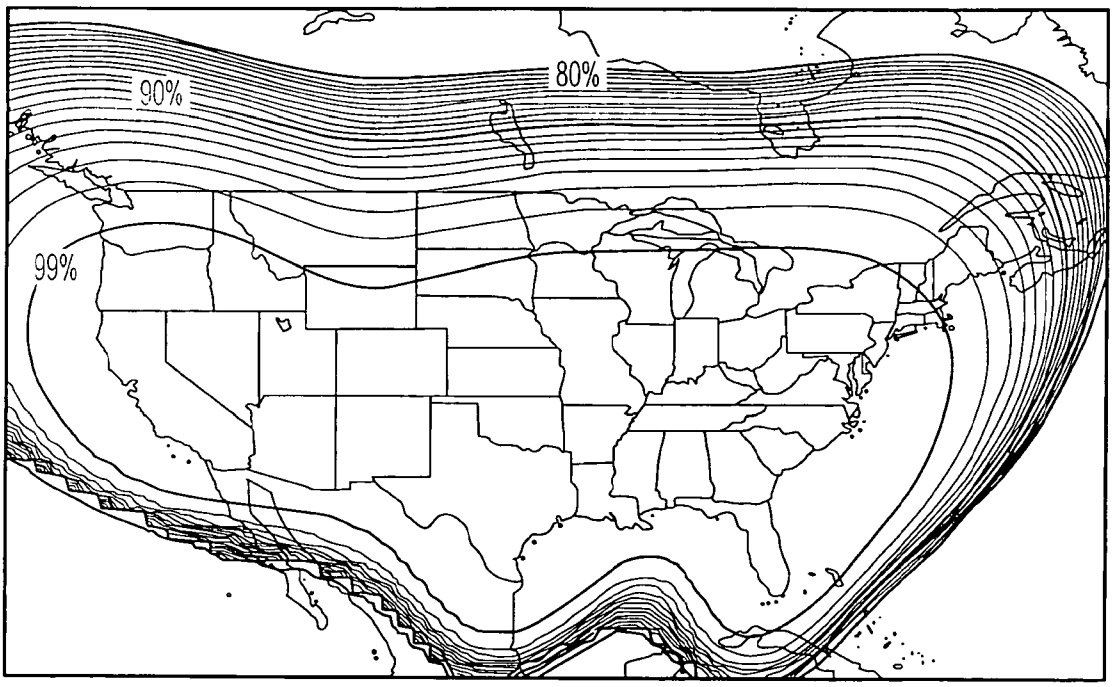


FIG. 14
PRIOR ART

	STATION NUMBER	DESIRED AVAILABILITY (115)	REQUIRED EIRP IN dBW (115)		REQUIRED EIRP IN dBW (85)	DESIRED AVAILABILITY (FOR PAIR)	COMMENT
INITIAL SPECIFICATION	1	90%	62.3	90%	67.7	99.0%	INDEPENDENT OPTIMIZATION REQUIRES UNREALIZABLE EIRP FOR THIS LOCATION FOR ONE SATELLITE (85). IN ADDITION, PRODUCING THIS EIRP AT SUCH A LOW ELEVATION PRODUCES UNACCEPTABLE SPILL-OVER OUTSIDE OF THE COVERAGE AREA.
ADJUSTED SPECIFICATION	1	95%	66.5	80%	63.7	99.0%	SECOND ATTEMPT REQUIRES EIRP WHICH IS TOO HIGH FOR OTHER SATELLITE.
THIRD ATTEMPT AT REASONABLE SPECIFICATON	1	94%	65.5	83%	65.0	99.0%	THIRD ATTEMPT HAS ACHIEVABLE EIRP FOR BOTH SATELLITES AND MEETS JOINT AVAILABILITY REQUIREMENT. IF IT DIDN'T THE JOINT AVAILABILITY SPEC WOULD NEED TO BE RELAXED.

ASSUMES EIRP LIMIT OF 66dBW CLOSE TO EDGE OF COVERAGE FOR EACH SATELLITE

FIG. 15
PRIOR ART

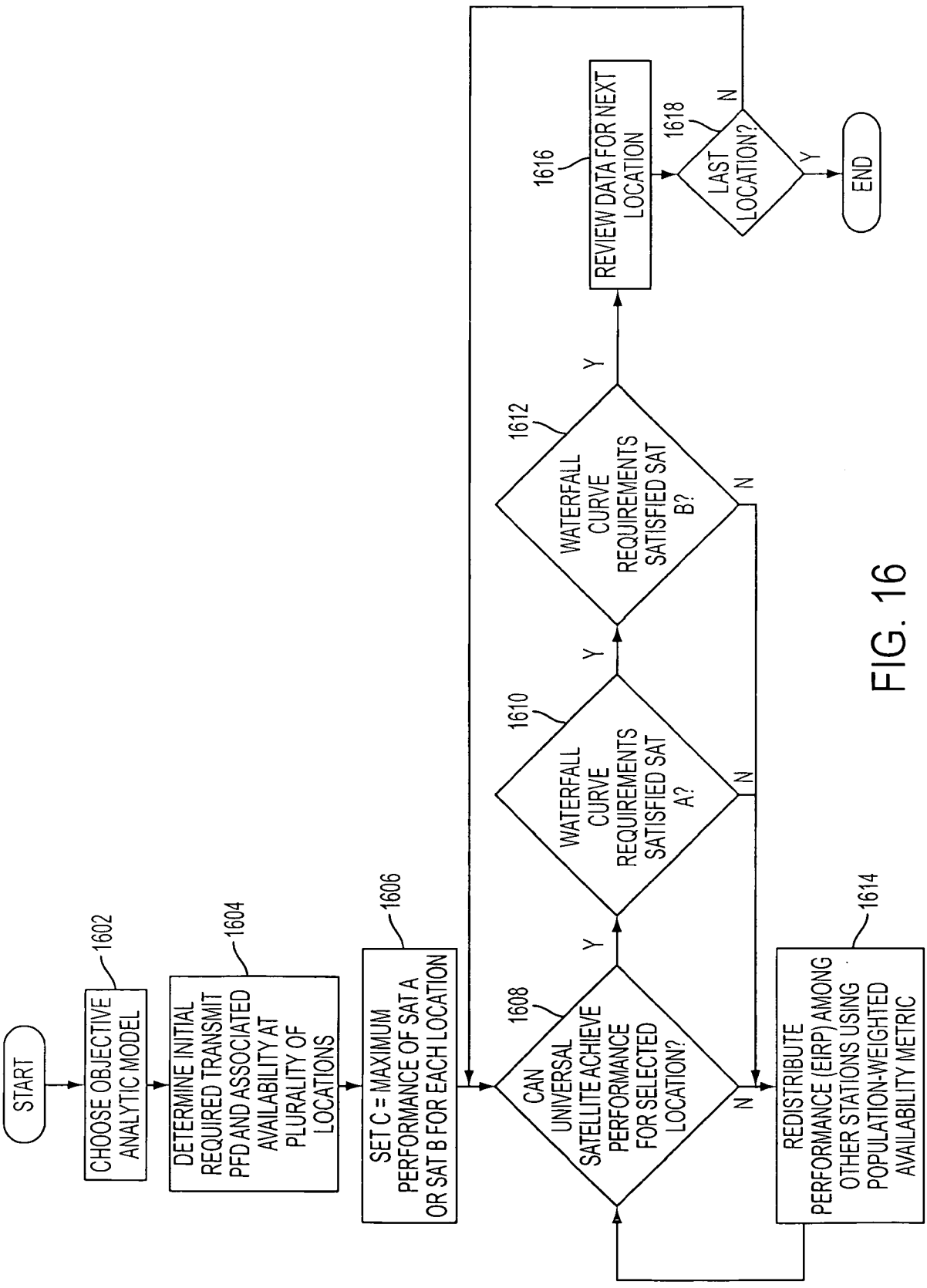
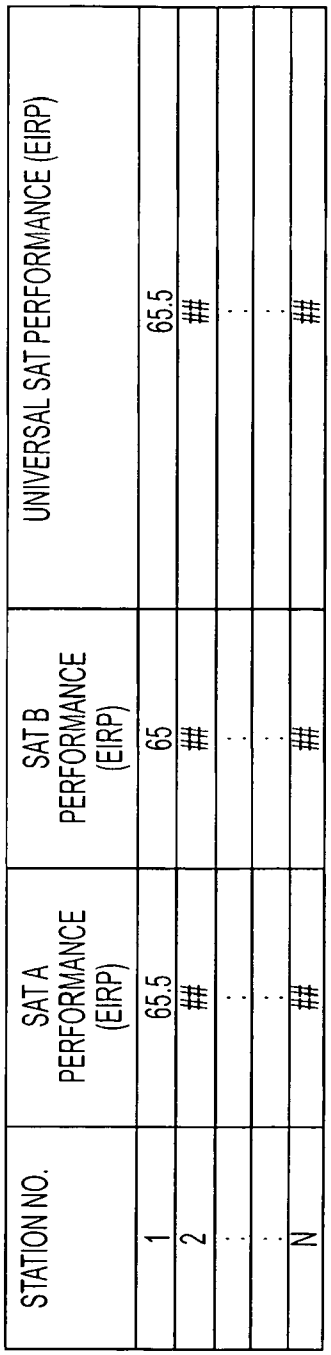

START
CHOOSE OBJECTIVE ANALYTIC MODEL
1602
DETERMINE INITIAL REQUIRED TRANSMIT PFD AND ASSOCIATED AVAILABILITY AT PLURALITY OF LOCATIONS
1604
SET C = MAXIMUM PERFORMANCE OF SAT A OR SAT B FOR EACH LOCATION
1606
CAN UNIVERSAL SATELLITE ACHIEVE PERFORMANCE FOR SELECTED LOCATION?
1608
Y
N
WATERFALL CURVE REQUIREMENTS SATISFIED SAT A?
1610
Y
N
WATERFALL CURVE REQUIREMENTS SATISFIED SAT B?
1612
Y
N
REDISTRIBUTE PERFORMANCE (EIRP) AMONG OTHER STATIONS USING POPULATION-WEIGHTED AVAILABILITY METRIC
1614
REVIEW DATA FOR NEXT LOCATION
1616
LAST LOCATION?
1618
Y
N
END

FIG. 16



STATION NO.	SAT A PERFORMANCE (EIRP)	SAT B PERFORMANCE (EIRP)	UNIVERSAL SAT PERFORMANCE (EIRP)
1	65.5	65	65.5
2	##	##	##
. .	. .	. .	. .
. .	. .	. .	. .
N	##	##	##

FIG. 17

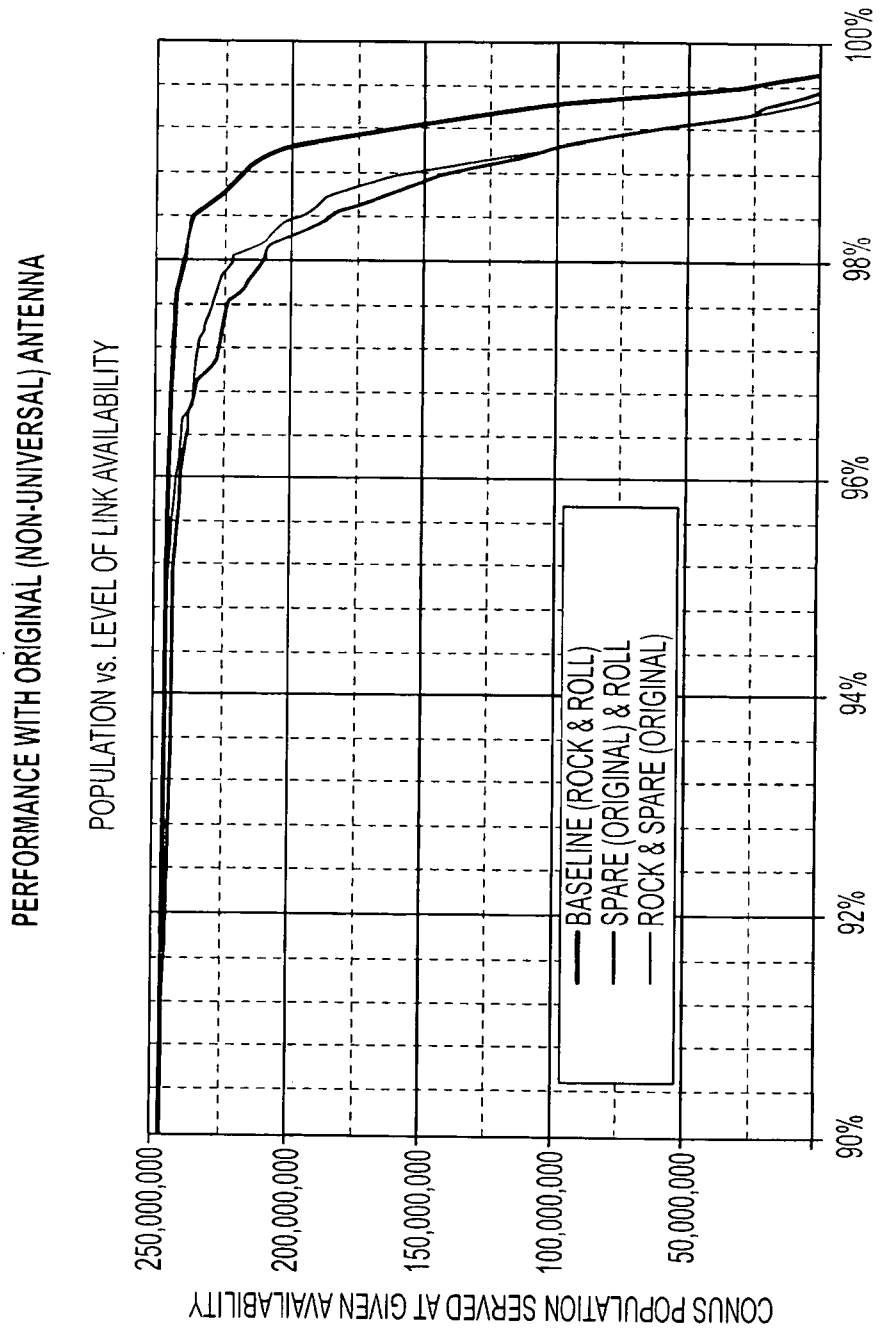

PERFORMANCE WITH ORIGINAL (NON-UNIVERSAL) ANTENNA
POPULATION vs. LEVEL OF LINK AVAILABILITY
CONUS POPULATION SERVED AT GIVEN AVAILABILITY
250,000,000
200,000,000
150,000,000
100,000,000
50,000,000
90%
92%
94%
96%
98%
100%
AVAILABILITY
BASELINE (ROCK & ROLL)
SPARE (ORIGINAL) & ROLL
ROCK & SPARE (ORIGINAL)

FIG. 18

IN-ORBIT SPARE SATELLITE
AVAILABILITY PERFORMANCE - ORIGINAL ANTENNA

CASE	DESCRIPTION	AVAILABILITY*
ROCK & ROLL	BASELINE	95% MINIMUM 99.7% MAXIMUM 99.23% POPULATION WEIGHTED AVERAGE
ROCK & SPARE (ORIGINAL)	ROLL SATELLITE FAILS; SPARE SATELLITE (WITH ORIGINAL REFLECTORS) REPLACES IT	87.7% MINIMUM 98.4% MAXIMUM 98.35% POPULATION WEIGHTED AVERAGE
SPARE (ORIGINAL) & ROLL	ROCK SATELLITE FAILS; SPARE SATELLITE (WITH ORIGINAL REFLECTORS) REPLACES IT	93.5% MINIMUM 99.5% MAXIMUM 98.47% POPULATION WEIGHTED AVERAGE

** MIN AND MAX OF 242 CITY LOCATIONS IN CONUS, POPULATION WEIGHTED AVERAGE USES STATE POPULATIONS AND ASSUMES STATE POPULATION ARE EQUALLY SPLIT AMONG CITIES WITHIN A STATE*

FIG. 19

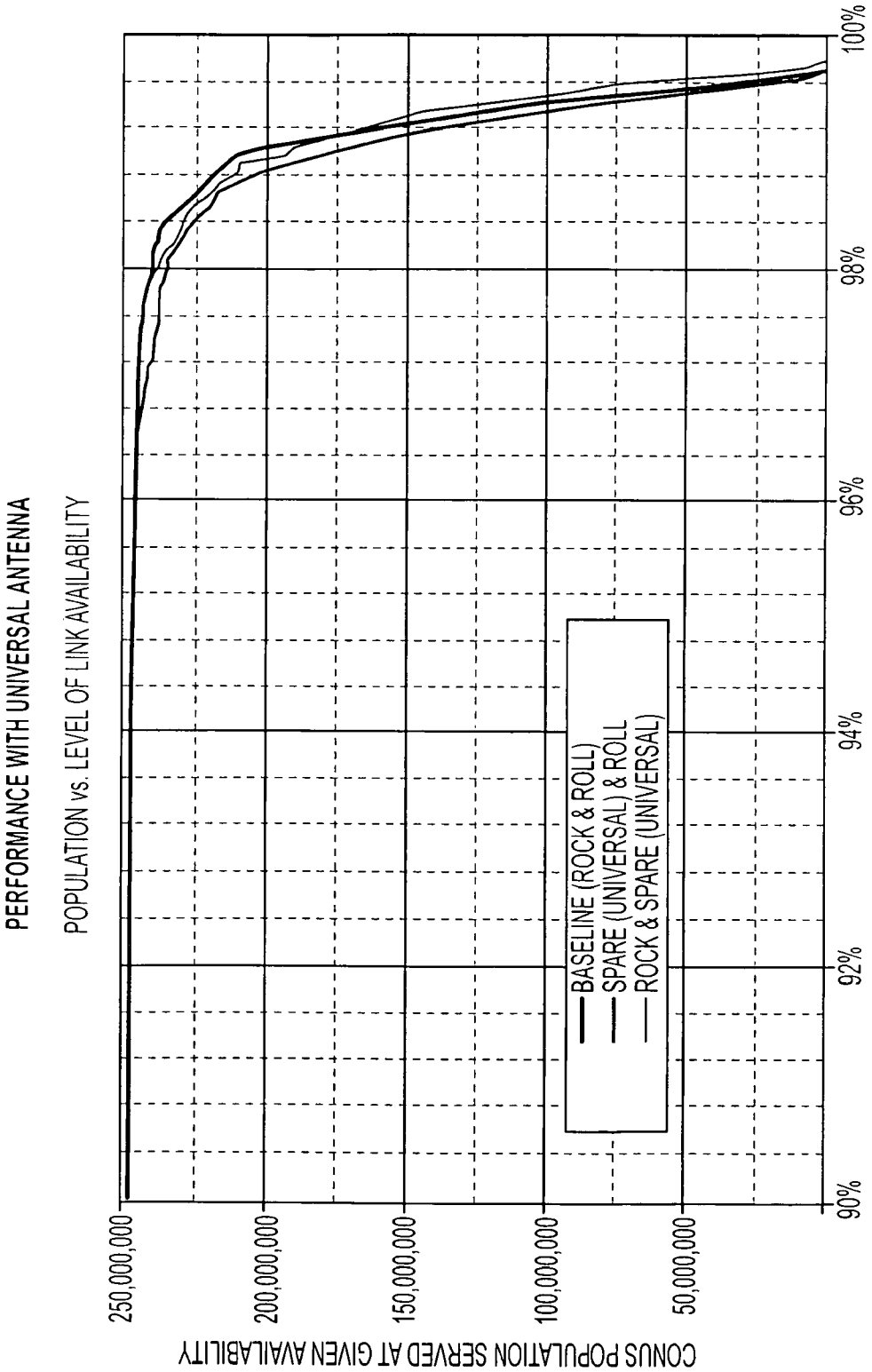

PERFORMANCE WITH UNIVERSAL ANTENNA
POPULATION vs. LEVEL OF LINK AVAILABILITY
CONUS POPULATION SERVED AT GIVEN AVAILABILITY
250,000,000
200,000,000
150,000,000
100,000,000
50,000,000
90%
92%
94%
96%
98%
100%
AVAILABILITY
BASELINE (ROCK & ROLL)
SPARE (UNIVERSAL) & ROLL
ROCK & SPARE (UNIVERSAL)

FIG. 20

IN-ORBIT SPARE SATELLITE
AVAILABILITY PERFORMANCE - ANTENNA

CASE	DESCRIPTION	AVAILABILITY*
ROCK & ROLL	BASELINE	95% MINIMUM 99.7% MAXIMUM 99.23% POPULATION WEIGHTED AVERAGE
ROCK & SPARE (UNIVERSAL)	ROLL SATELLITE FAILS; SPARE SATELLITE (WITH UNIVERSAL REFLECTORS) REPLACES IT	92.0% MINIMUM 99.6% MAXIMUM 98.68% POPULATION WEIGHTED AVERAGE
SPARE (UNIVERSAL) & ROLL	ROCK SATELLITE FAILS; SPARE SATELLITE (WITH UNIVERSAL REFLECTORS) REPLACES IT	93.9% MINIMUM 99.6% MAXIMUM 98.71% POPULATION WEIGHTED AVERAGE

** MIN AND MAX OF 242 CITY LOCATIONS IN CONUS, POPULATION WEIGHTED AVERAGE USES STATE POPULATIONS AND ASSUMES STATE POPULATION ARE EQUALLY SPLIT AMONG CITIES WITHIN A STATE*

FIG. 21

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2008/014122

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H04B 7/06 (2009.01)
USPC - 455/101
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - H04B 7/06 (2009.01)
USPC - 342/352, 360; 375/299, 347, 349; 455/12.1, 13.2, 101

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPTO EAST System (US, USPG-PUB, EPO, DERWENT), Google Patents

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,470,058 B1 (MICHALSKI et al) 22 October 2002 (22.10.2002) entire document	1-10
Y	US 6,192,217 B1 (FARRELL) 20 February 2001 (20.02.2001) entire document	1-10
Y	US 2003/0155468 A1 (GOODZEIT) 21 August 2003 (21.08.2003) entire document	1-10

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 April 2009	16 APR 2009
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (April 2005)