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(54) Method and apparatus for cancelling interference between area coverage and spot coverage antenna beams.

(57) The present invention relates to method and apparatus for substantially cancelling interference between signals using the same frequency spectrum which are received via overlapping area coverage (12) and spot coverage (e.g. 14a) antenna beams. At the transmitter where the overlapping area and spot coverage beams are concurrently transmitted, a predetermined portion of the area coverage signal is coupled into each of the spot beam signals which will be overlapped at the associated spot beam receiver area by the area coverage beam.

The predetermined portion coupled into each spot beam signal will have a magnitude and phase to substantially cancel the area coverage signal at the associated spot beam receiver area.

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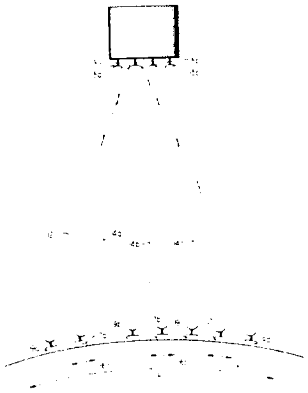
FIG 1



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METHOD AND APPARATUS FOR CANCELLING INTERFERENCE BETWEEN AREA COVERAGE AND SPOT COVERAGE ANTENNA BEAMS

The present invention relates to method and apparatus for effecting substantial cancellation of interference between a first and a second signal transmitted concurrently in a first and a second antenna radiated beam, respectively, where the first and second signals include different informational content and use the same frequency spectrum and the first and second beams overlap each other in the area of a receiver which is to receive only the first signals.

In a domestic satellite communication system the coexistence of spot and area coverage beams can be desirable. For example, a separate spot coverage beam can be used for communication between the satellite and each high traffic ground station while an area coverage beam can be used for communication between the satellite and a plurality of low traffic ground stations under conditions where it might not be desirable to interconnect the individual low traffic ground stations to a nearest high traffic ground station for access to the satellite system. To avoid signal degradation and permit separation of the overlapping spot coverage and area coverage beams, especially at each spot coverage receiving station, a typical prior art technique would be to use separate bandwidths or polarizations, if possible, for the spot coverage beams and the area coverage beam. Using separate bandwidths, however, results in inefficient use of the frequency spectrum and different polarizations may not be available where dual polarized beams are already used by each of the beams of the satellite system.

Various techniques have been devised to suppress interference between two beams arriving at a receiver from separate directions. In this regard see, for instance, U.S. Patents 2,520,184; 3,094,695; 3,369,235 and 3,987,444. Since the area and spot coverage beams transmitted from a satellite arrive at each spot beam ground station from the same direction, techniques for separating signals arriving from different directions are not usable.

An alternative technique to enable reception of only one signal of a plurality of signals concurrently received from a plurality of transmitters at an FM receiver would be to modulate the carrier of each transmitter with a separate frequency to provide a unique address that is assigned to an associated receiver as disclosed, for example, in U.S. Reissue Patent Re. 27,478. Such arrangement may be applicable to FM communication systems but does not appear applicable to a digital communication system.

The problem remaining in the prior art is to provide a technique which permits overlapping spot and area coverage beams which use the same frequency band to be separated at an overlapped receiving station.

The foregoing problem is solved according to the invention by the method characterized by the step of, at the transmitter, coupling a predetermined portion of the second signal to be transmitted in the second beam into the signal to be transmitted by the first beam, said predetermined portion of the coupled-in second signal having a magnitude and phase to cancel substantially, after propagation in the first beam to the receiver, the second signal which arrives in the second beam at the receiver. For practizing the above recited method, the invention provides for a transmitter characterized by a first antenna capable of transmitting the first beam with a predetermined field pattern $E_s(\theta)$ in the direction of the receiver which is to receive only the first signals; a second antenna capable of transmitting the second beam with a predetermined filed pattern $E_A(\theta)$ which overlaps said first beam field pattern in the area of the receiver which is to receive only the first signals; a first transmission line capable of delivering the signal to be transmitted in the first beam to the first antenna; a second transmission line capable of delivering the signal to be transmitted in the second beam to the second antenna, and a coupler disposed between the first and second transmission lines arranged to couple a predetermined portion of the second signal propagating in the second transmission line into the first transmission line for transmission in the first beam, the predetermined portion of the second signal coupled into the first transmission line having a magnitude and phase to substantially cancel the signal in the second beam arriving at the first beam receiver.

The present invention has been described primarily in relationship to a satellite communication system to enable the concurrent use of an area coverage satellite radiated beam and a plurality of spot coverage satellite radiated beams where all of the beams use the same frequency spectrum and the spot coverage beams are received within the area encompassed by the area coverage beam. However, it will be understood that such description is exemplary only and is for the purpose of exposition and not for purposes of limitation. It will be readily appreciated that the inventive concept described is equally applicable to other radiated wave transmission systems which comprise two or more beams which have different destinations but interfere with each other at one or more of the destinations.

In the drawings:

FIG. 1 diagrammatically illustrates a satellite communication system for providing both an area coverage beam and a plurality of spot coverage beams between the satellite and the associated ground receiver stations;

FIG. 2 illustrates an arrangement according to the present invention to effect interference cancellation of the area coverage beam at each of the spot coverage receiver stations;

FIG. 3 is a curve illustrating the antenna pattern of a spot coverage beam and a modified area coverage beam in the area of a spot coverage ground station according to the present invention;

FIG. 4 is a curve illustrating the Signal-to-Interference ratio at the ground stations between a spot coverage beam and the modified area coverage beam in accordance with the arrangement of FIG. 2;

FIG. 5 is a curve illustrating the power spectrum of a 4Φ- PSK signals for a 300 Mbauds spot beam and two 75 Mbauds area beams in accordance to the present invention.

In FIG. 1, a satellite communication system is illustrated wherein the present invention is especially useful to permit the concurrent transmission from a satellite 10 of both an area coverage beam 12 and a plurality of spot coverage beams of which, for example, three beams 14a, 14b and 14c are shown with all beams being able to use the same frequency spectrum. Spot coverage beams 14a, 14b and 14c are shown radiating from antennas 15a, 15b and 15c, respectively, and directed at respective ground areas 16a, 16b and 16c which include for example, high traffic ground stations 17a, 17b and 17c, respectively. Area coverage beam 12 is shown radiating from an antenna 13 and directed at a ground area 18 which includes both the ground areas 16a, 16b and 16c and a plurality of low traffic ground stations of which, for example, four stations 19a-19d are shown. In the satellite communication system of FIG. 1, each of the high traffic ground stations 17a-17c communicates with satellite 10 via a separate spot beam 14a-14c, respectively, while the low traffic ground stations 19a-19d communicate with satellite 10 via common area coverage beam 12 using any suitable technique to assure that a particular message will be processed by only the appropriate one of stations 19a-19d. Such arrangement permits low traffic ground stations 19a-19d to communicate with satellite 10 under conditions where it is not advantageous to connect a low traffic ground station 19 to a nearby one of high traffic ground stations 17a-17c.

It can be seen from FIG. 1 that when area coverage beam 12 and spot coverage beams 14a-14c are transmitted concurrently and use the same frequency spectrum that each of ground stations 17a-17c will receive both the associated one of spot coverage beams 14a-14c and area coverage beam 12 since these beams emmanate from approximately the same point and most probably the same antenna rather than separate antennas as shown in FIG. 1. Under such conditions the use of prior art arrangements such as, for example, side lobe suppression arrangements to select a wave received from a particular direction over waves received from other directions is not feasible.

The concurrent transmission of area coverage beam 12 and a plurality of spot coverage beams 14a-14c using the same frequency spectrum can be effected in accordance with the present invention by the arrangement shown in FIG. 2. For purposes of explanation, S_s represents the signal intended for a particular spot beam antenna 15 with a field pattern $E_s(\theta)$. More particularly, signals S_{s_a}, S_{s_b} and S_{s_c} propagate in waveguide 21a, 21b and 21c, respectively, to respective antennas 15a, 15b and 15c for radiation to respective ground stations 17a-17c via spot coverage beams 14a, 14b and 14c, respectively. The field pattern $E_s(\theta)$ for each of the spot coverage beams 14 is assumed to be of Gaussian shape as, for example, in the main lobe of a paraboloid fed by a corrugated feedhorn, and is given by:

$$E_s(\theta) = E_s(0)\, e^{-\frac{1}{2}(0.833\ \theta/\theta_{3\ \mathrm{dB}})^2}\ , \qquad (1)$$

where $E_s(0)$ is in the magnitude of the field along the axis of each spot coverage beam 14. Additionally, S_A represents the signal intended for area coverage beams 12 and is shown propagating in waveguide 21d to antenna 13 for radiation to ground stations 19 via area coverage beam 12 which has a field pattern $E_A(\theta)$ which is given by

$$E_A(\theta) = E_A(0)\ , \qquad (2)$$

where $E_A(0)$ is the magnitude of the field along the axis of area coverage beam 12.

Since $E_A(\theta)$ represents the field pattern over area 18 of FIG. 1, it is desirable to produce a "hole" in $E_A(\theta)$ in the areas 16a-16c where the spot coverage beams 14a-14c exist such that E_A does not interfere with each of the E_s patterns. In accordance with the present invention, interference between the signal S_A transmitted via area coverage beam 12 and each of signals S_{s_a}, S_{s_b} and S_{s_c} transmitted via spot coverage beams 14a, 14b and 14c, respectively, is substantially reduced at each of the spot beam ground stations 17 by coupling a portion of the area coverage signal, S_A, propagating in waveguide 21d, into each of the spot coverage signals S_{s_a}, S_{s_b} and S_{s_c} propagating in waveguides 21a-21c, respectively, using respective directional couplers 22a, 22b and 22c. To accomplish such interference cancellation at each of ground stations 17, each of couplers 22a-22c should preferably have a negative coupling coefficient of approximately between one and two times the value of $\frac{E_A(0)}{E_s(0)}$. For example, for a negative coupling coefficient of 1.21, the radiated signal for area beam 12 and one of spot beams 14a-14c in the vicinity of the associated spot beam ground station 17 then becomes

$$y(\theta) = E_A(\theta)\left[1 - 1.21\,\frac{E_A(0)}{E_s(0)}\,\frac{E_s(\theta)}{E_A(\theta)}\right] S_A$$

$$+\; E_s(\theta)\left[1 - 1.21\,\frac{E_A(0)}{E_s(0)}\,\frac{E_A(\theta)}{E_s(\theta)}\right] S_s. \quad (3)$$

Since $E_s(0) \gg E_A(0)$, Equation (3) can be simplified to

$$y(\theta) \quad E_A(\theta)\left[1 - 1.21\,\frac{E_s(\theta)}{E_s(0)}\right] S_A + E_s(\theta)\, S_s. \quad (4)$$

The normalized power patterns for both a spot and the area coverage beams are

$$E_s(\theta)/E_s(0)\ ^2 \quad \text{and} \quad E_A(\theta)\ (1 - 1.21\frac{E_s(\theta)}{E_s(0)})/E_A(0)\ ^2$$

and are shown in FIG. 3. From FIG. 3 it can be seen that the spot coverage beam 14 remains unchanged when received at associated area 16 whereas the area coverage beam 12 is significantly reduced in the spot coverage beam region 16.

If it is assumed that 4Φ-PSK modulation of the same baud rate is used in both beams and that the Effective Instantaneous Radiated Power (EIRP) at beam peaks are the same, i.e., $< E_A(0)S_A\ ^2> = < E_s(0)S_s\ ^2>$, the signal to interference ratio (S/I) at the ground defined by P_A/P_s or P_s/P_A is shown in FIG. 4 by a solid line, where

P_A = received power of S_A ($E_A(\theta)[1-1.21\frac{E_s(\theta)}{E_s(0)}]S_A\ ^2$) and

P_s = received power of S_s ($E_s(\theta)S_s$). From FIG. 4, it can be seen that if S/I > 14 dB is acceptable, the far field region breaks down to

$0 \lesssim \theta \lesssim \theta_{3\ dB}$	Spot Beam (P_s/P_A > 14 dB)
$\theta_{3\ dB} \lesssim \theta \lesssim 2.25\ \theta_{3\ dB}$	Blackout region
$2.25\ \theta_{3\ dB} \lesssim \theta$	Area Beam (P_A/P_s > 14 dB)

The blackout region is that area which is serviceable by neither the area beam nor the spot beam because of mutual interference between the two beams. The traffic terminating in the blackout region at the edge of each of spot beam regions 16 may have to be trunked on the ground via other stations in the neighboring region.

If advantage is taken of the spectrum shape of the 4Φ-PSK signal, the blackout region can be reduced or the S/I may be increased. For example, the capacity of the area coverage beam can be reduced by a factor of two and the modulations can be placed at the edges of the allocated 500 MHz bandwidth of the satellite downlink. The power spectrums of a 300 Mbauds spot coverage beam and two 75 Mbauds area beams are shown in FIG. 5. It should be noted that a ground station 19, intended to receive the area coverage beam 12, will have a receiving filter having characteristics which follow either spectrum A_1 or A_2. Therefore, the received interference power of S_s is reduced by about 6 dB due to this offsetting of modulation spectrum. Similarly, a ground station 17 intended to receive S_s will have a receiving filter having characteristics which follow spectrum S in FIG. 5. The received power of S_A is reduced by about 9 dB compared to that of S_s.

Taking into account both the S/I improvement obtained by spectrum offsetting (FIG. 5) and the antenna pattern discrimination, the resultant $(P_s/P_A)'$ and $(P_A/P_s)'$ are shown by a dashed line in FIG. 4.

In FIG. 4 it can be seen that the blackout region is reduced using spectrum offsetting and antenna pattern discrimination. Again for S/I > 14 dB, the regions for $(P_s/P_A)'$ and $(P_A/P_s)'$ becomes:

$0 < \theta < 1.2\ \theta_{3\ dB}$ Spot Beam $(P_s/P_A)' > 14$ dB

$1.2\ \theta_{3\ dB} \leq \theta \leq 1.85\ \theta_{3\ dB}$ Blackout Region

$1.85\ \theta_{3\ dB} \leq \theta$ Area Beam $(P_A/P_s)' > 14$ dB

Compared to the previous case using only the arrangement of FIG. 2, the blackout region has been reduced to $(1.85 - 1.2)^2/(2.25 - 1)^2 = 27$ percent. Or, if maintaining the same blackout region, the minimum S/I in the serviceable region would be higher than 20 dB.

1. The method of effecting substantial cancellation of interference between a first and a second signal transmitted concurrently in a first and a second antenna radiated beam, respectively, where the first and second signals include different informational content and use the same frequency spectrum and the first and second beams overlap each other in the area of a receiver which is to receive only the first signals, the method characterized by the step of:

at the transmitter

(a) coupling a predetermined portion of the second signal to be transmitted in the second beam into the signal to be transmitted by the first beam, said predetermined portion of the coupled-in second signal having a magnitude and phase to cancel substantially, after propagation in the first beam to the receiver, the second signal which arrives in the second beam at the receiver.

2. The method according to claim 1 characterized by, prior to said step (a), performing the steps of

(b) providing a signal capacity for the second beam which is less than the signal capacity of the first beam; and

(c) modulating the second beam signal in a manner to divide the power spectrum for the second beam signal into two portions with each portion disposed both within the frequency spectrum of the first beam and near separate edges of said frequency spectrum.

3. The method according to claim 1 or 2, characterized in that the first beam is a spot coverage beam (14a,14b,14c) and the second beam is an area coverage beam (12).

4. A transmitter for practizing the method of claim 1, characterized by

a first antenna (15) capable of transmitting the first beam (14) with a predetermined field pattern ($E_s(\theta)$ in the direction of the receiver which is to receive only the first signals;

a second antenna (13) capable of transmitting the second beam (12) with a predetermined field pattern $E_A(\theta)$ which overlaps said first beam field pattern in the area of the receiver which is to receive only the first signals;

a first transmission line (21a) capable of delivering the signal to be transmitted in the first beam to said first antenna

a second transmission line (21d) capable of delivering the signal to be transmitted in the second beam to said second antenna

a coupler (22a) disposed between said first and second transmission lines arranged to couple a predetermined portion of the second signal propagating in said second transmission line into said first transmission line for transmission in the first beam, said predetermined portion of the second signal coupled into said first transmission line having a magnitude and phase to substantially cancel the signal in the second beam arriving at the first beam receiver.

5. A transmitter according to claim 3 characterized in that said coupler comprises a directional coupler (22a) having a predetermined negative coupling coefficient.

6. A transmitter according to claim 5 characterized in that said predetermined negative coupling coefficient has a value approximately equal to between one and two times the factor $\frac{E_A(0)}{E_s(0)}$, where $E_s(0)$ and $E_A(0)$ are the magnitude of the fields along the axes of the first and second antenna radiated beams (14, 12), respectively.

7. A transmitter according to claims3, 4, 5 or 6 characterized in that

the second beam (12) is provided with a capacity which is less than the signal capacity of the first beam (14); and the transmitter a modulator capable of modulating the second beam signal in a manner to divide the power spectrum for the second beam signal into two portions with each portion disposed both within the frequency spectrum of the first beam and near separate edges of said frequency spectrum.

FIG. 1

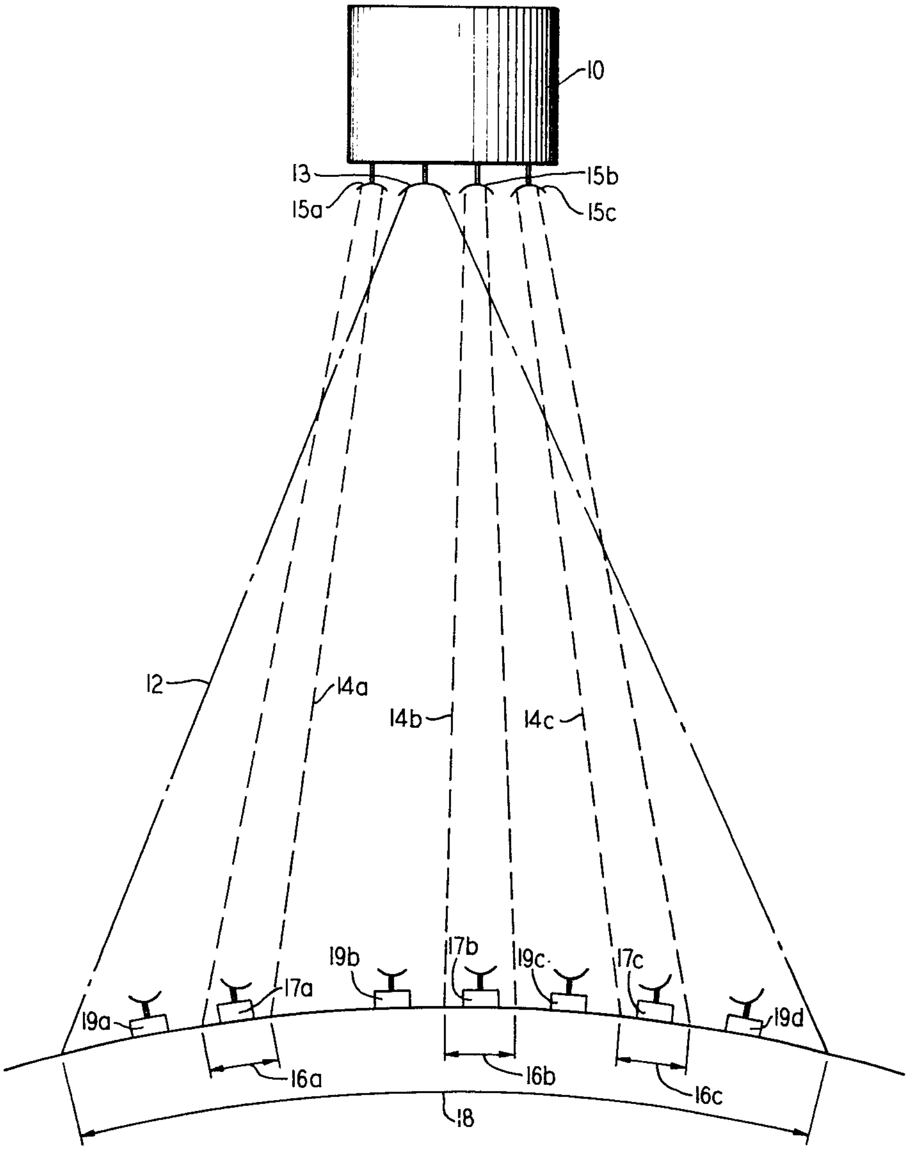

10
13
15b
15a
15c
12
14a
14b
14c
19b
17b
19c
17c
17a
19a
19d
16a
16b
16c
18

FIG. 2

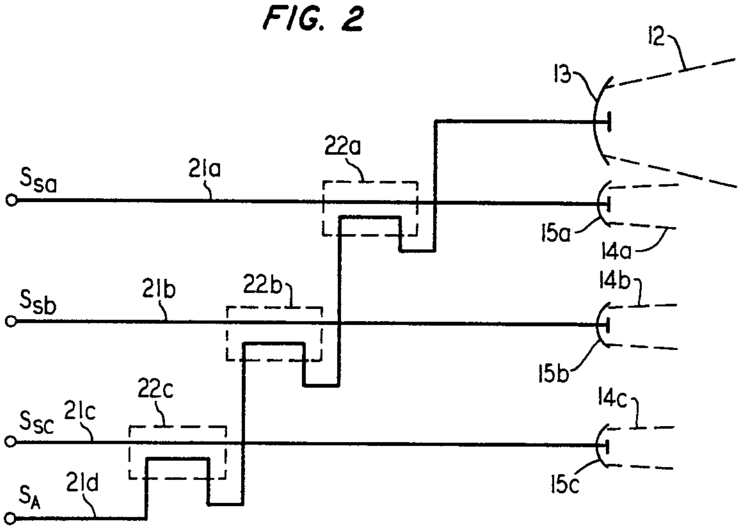

12
13
22a
S_{sa}
21a
15a
14a
14b
22b
S_{sb}
21b
15b
22c
14c
S_{sc}
21c
15c
S_A
21d

FIG. 3

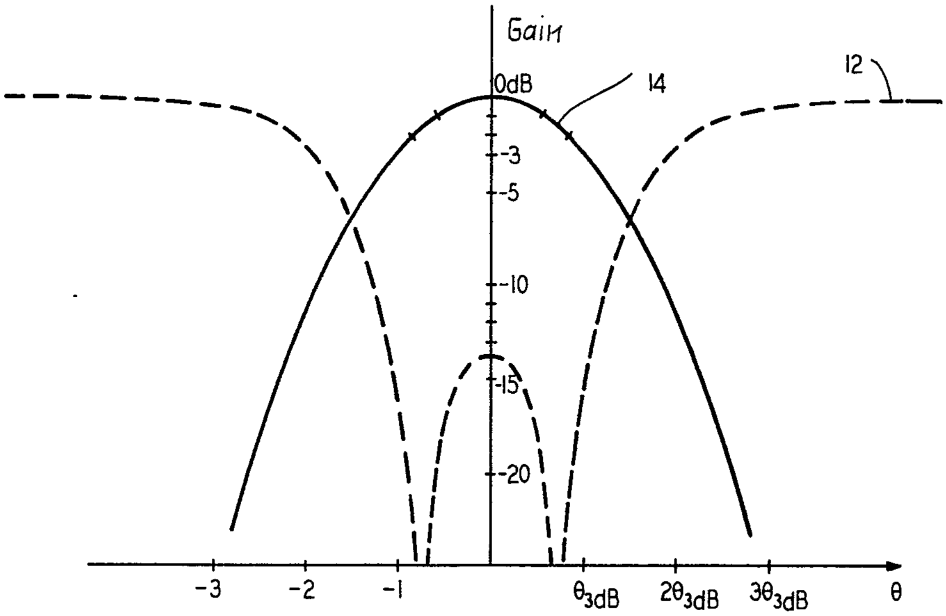

Gain
0dB
14
12
-3
-5
-10
-15
-20
-3
-2
-1
θ_{3dB}
$2\theta_{3dB}$
$3\theta_{3dB}$
θ

FIG. 4

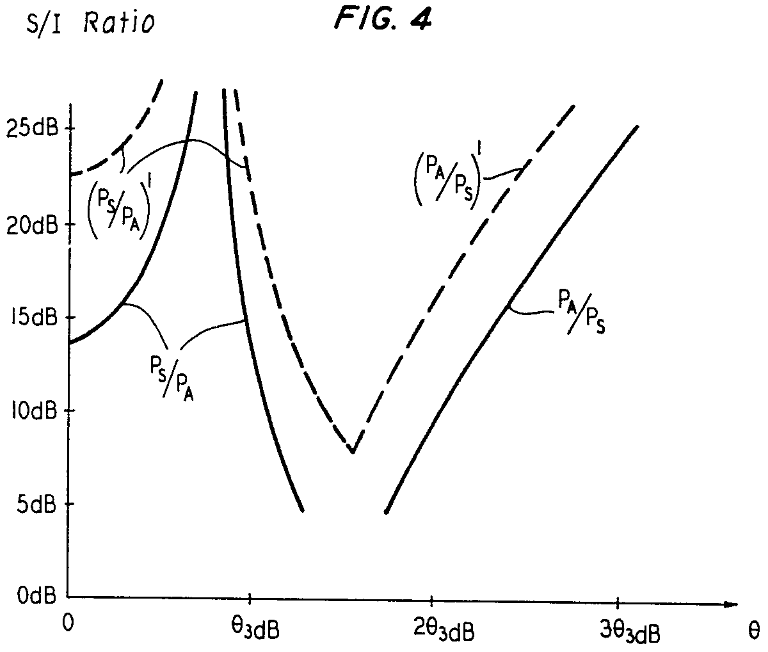
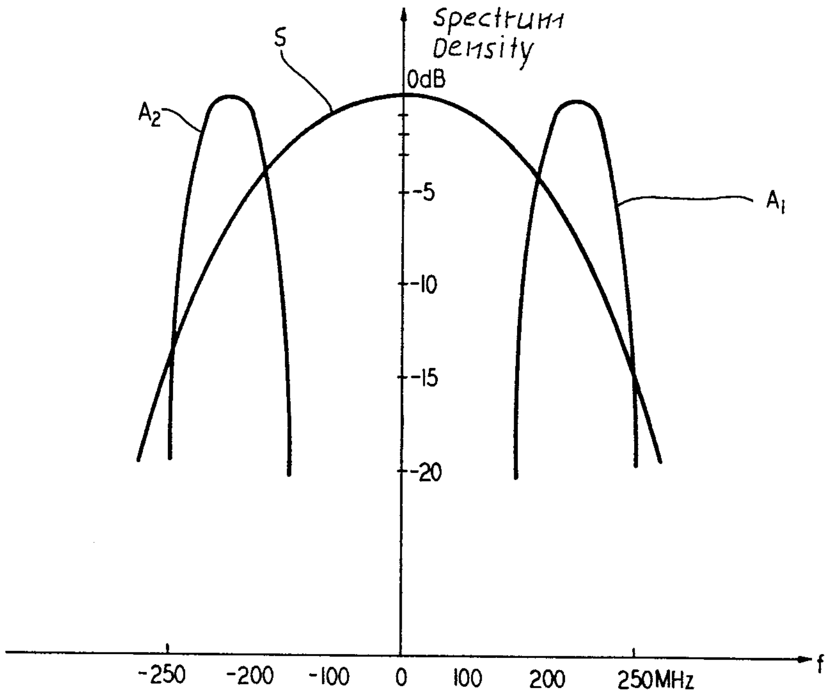

S/I Ratio
25dB
20dB
15dB
10dB
5dB
0dB
0
θ3dB
2θ3dB
3θ3dB
θ
(PS/PA)'
PS/PA
(PA/PS)'
PA/PS

FIG. 5


Spectrum Density
0dB
-5
-10
-15
-20
S
A2
A1
-250
-200
-100
0
100
200
250MHz
f

European Patent Office

EUROPEAN SEARCH REPORT

0000038

Application number

EP 78 10 0062

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
X	US - A - 3 325 816 (DUTTON) * Column 1, lines 3 to 5, 69 to 71; column 2, lines 1 to 4; figure 3 * --	1-3,5
	COLLOQUE INTERNATIONAL L'ESPACE ET LA COMMUNICATION, Chiron, 1971, Paris H.KABISCH et al."Study of a possible regional telecommunication satellite system for Europe", pages 279 to 292 * Page 282, lines 4 to 7; page 284, lines 25 to 27; page 285, lines 2 to 3 * --	1-3,7
	PROCEEDINGS OF THE IEEE, vol. 65, nr. 3, March 1977, New York L.J.RICARDI "Communication satellite antennas", pages 356 to 369 * Page 366, paragraph IX; figure 15 * --	1,3-5
	WESCON TECHNICAL PAPERS, vol. 19, 1975 (San Francisco, Sept.16-19,1975) New York, COL.H.WYNE & D.E.KENDALL "Defense satellite communication system in the 1980s.", Paper 32/5, pages 1 to 5 * Page 4, left-hand column, lines 6 to 11 * --	1,3,4
	US - A - 3 511 936 (SALTZBERG) * Column 2, lines 38 to 41; column 5, lines 11 to 14 * --	2-7
	./.	

CLASSIFICATION OF THE APPLICATION (Int. Cl.^{2})

H 04 B 7/185
H 01 Q 3/00

TECHNICAL FIELDS SEARCHED (Int.Cl.^{2})

H 04 B 7/185
H 01 Q 3/00
G 01 S 9/56
H 04 L 5/06

CATEGORY OF CITED DOCUMENTS

- X: particularly relevant
- A: technological background
- O: non-written disclosure
- P: intermediate document
- T: theory or principle underlying the invention
- E: conflicting application
- D: document cited in the application
- L: citation for other reasons
- &: member of the same patent family, corresponding document

☒ The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	04-09-1978	GEISLER

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EUROPEAN SEARCH REPORT

Application number

EP 78 10 0062

0000038

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.²)
P	IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS, (Chicago, June 12-15, 1977) New York, D.O.REUDINK et al."Spectral reuse in 12 GHz satellite communication systems", pages 37.5-32 to 37.5-35 * Totality * ----	1-7	
			TECHNICAL FIELDS SEARCHED (Int. Cl.²)