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The use of the 26 MHz band for satellite broadcasting

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Summary

The existing top h.f. band (25.6 – 26.1 MHz) might be more effectively used than at present for international broadcasting if transmissions from satellites were permitted. Although the World Administrative Radio Conference, Geneva, 1979 did not extend the use of the band in this way, the report gives a useful record of the technical studies made in the preparation for the Conference. Propagation factors which would limit such a service are examined and it is found that signals from a geostationary satellite could reach a large area around the subsatellite point (up to ±50° relative longitude and latitude) for a high percentage of time, day and night. Curves are presented also for two cases of a sub-synchronous satellite. Estimates for the r.f. transmitter power required vary from 1 to 5 kW depending on the orbit and whether narrow-band frequency modulation is used in place of conventional amplitude modulation.

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THE USE OF THE 26 MHz BAND FOR SATELLITE BROADCASTING

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1. Introduction

Unlike the other h.f. bands, whose effectiveness tends to be limited by congestion, the 26 MHz band (25.6 – 26.1 MHz) has limited usage at present because of propagation factors. With conventional transmitters it is suitable for international broadcasting (the main purpose of the band) only for a small proportion of time. For years near sunspot minimum it is not effective at any time of the day at any season of the year. The use of the 26 MHz band for sound broadcasting from satellites has therefore been proposed from time to time. In particular, it has been seriously considered by the European Broadcasting Union in considering proposals for the 1979 World Administrative Radio Conference and a feasibility study was undertaken by the BBC.[1] There was, however, little support for the proposal and, at the WARC, the broadcasting band was reduced to 25.67 to 26.1 MHz and kept for terrestrial use only.

This report, which is an expanded version of Reference 1, describes the technical factors which would control satellite broadcasting at 26 MHz and contains examples of power budgets for some possible systems. It does not consider the economic aspects.

The feasibility of satellite broadcasting at 26 MHz is very dependent on the effect of the ionosphere, which can shield the Earth and prevent transmissions reaching the service area. The ionosphere also affects the polarization of waves which traverse it and may cause attenuation, while it may enable signals which have reached the Earth to propagate into regions which are not directly illuminated. The influence of the ionosphere is discussed in the sections which follow.

2. Shielding by the ionosphere

In the normal ionosphere the F layer has the greatest electron concentration and therefore has the greatest shielding effect. The electron concentration of the sporadic-E layer, however, often exceeds that of the F layer. The shielding effects of both of these layers must therefore be taken into account.

Fig. 1 shows the geometry which applied to transmission through the ionosphere. Waves from the satellite S pass through the ionosphere at A and reach the Earth's surface at B. In traversing the ionosphere they suffer refraction and are displaced from the straight line SC, as shown in Fig. 1.

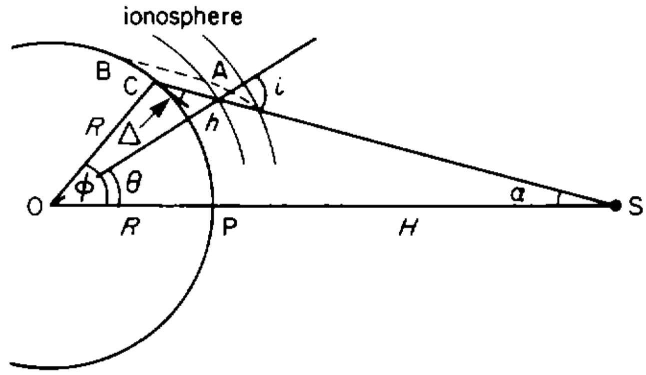

Fig. 1 - Path geometry

Reception at B depends on the state of the ionosphere at A, which may be as much as 2,000 km from B. To determine whether reception is possible at B it is necessary to determine the co-ordinates of the point A and calculate the angle of incidence i at the layer. The sideways displacement due to refraction is exaggerated in Fig. 1; it is usually small and can be ignored in preliminary calculations. If it has a significant effect it will increase the area served by the satellite beyond that predicted.

In the absence of refraction the path from the satellite to Earth would be the straight line SC. If the co-ordinates of C are specified, the angular distance ϕ to the sub-satellite point P is known. What is required is a knowledge of where the path passes through the critical ionospheric layer, in terms of the angular distance θ to the point below the ionosphere, and the angle of incidence i at the ionosphere itself.

The most convenient way to solve the geometry is to postulate an angle of arrival Δ (measured from the tangent plane, as shown in Fig. 1) even though this angle is of no great interest in this application. The relationships between θ and ϕ, and between i and ϕ, can then be established by means of the following equations:

$$\sin \alpha = \frac{R \cos \Delta}{R + H} \qquad (1)$$

$$\sin i = \frac{R \cos \Delta}{R + H} \qquad (2)$$

$$\phi = 90^\circ - \alpha - \Delta \qquad (3)$$

$$\theta = i - \alpha \qquad (4)$$

where R = radius of Earth (6,370 km)
H = height of satellite above sub-satellite point
h = height of ionosphere layer above ground.

Three values of the satellite height H are considered in the sections which follow. The largest value (35,786 km) applies to a satellite in a synchronous equatorial orbit. A number of sub-synchronous equatorial orbits are possible, as indicated in Table I of CCIR Report 215-4.[2] Two examples are considered here. A satellite at a height of 13,940 km makes two passes per day through a given longitude and may be particularly suitable for sound broadcasting if morning and evening transmissions are all that are required. The other example (H = 4,190 km) is the lowest height likely to be of interest, and the satellite would make seven passes per day.

2.1. Shielding by the F layer

The shielding effect of the F layer is determined by its critical frequency; this is the highest frequency at which normally-incident waves are reflected. As the critical frequency of the F layer never exceeds 20 MHz, normally-incident 26 MHz transmissions will always penetrate.

At oblique incidence, 26 MHz waves will penetrate provided the critical frequency in MHz is less than 26 cos i. At a height of 300 km, cos i cannot be less than 0.3 because waves pass obliquely through the ionosphere even when they arrive tangentially at the Earth's surface. Consequently 26 MHz transmissions will penetrate to all visible parts of the Earth's surface if the critical frequency of the F layer is less than 8 MHz. This condition is nearly always satisfied at night in temperate latitudes. Somewhat higher critical frequencies may occur at night near the equator but 26 MHz transmissions from satellites in equatorial orbits can always reach equatorial regions with a sufficiently steep angle of incidence. It is reasonable to conclude that the F layer is unlikely to act as a screen during the night.

In daytime the F layer usually divides into two distinct layers. The upper of these two layers, known as the F2 layer, has the greater electron concentration and therefore the greater screening effect. Since critical frequencies are much greater during the day than at night, the screening effect of the F2 layer is of prime importance.

The critical frequency of the F2 layer varies considerably from day to day and with geographic latitude and solar activity. Maps showing monthly median critical frequencies are contained in CCIR Report 340,[3] where they are denoted by EJF(ZERO)F2. Table I of CCIR Report 252-2[4]

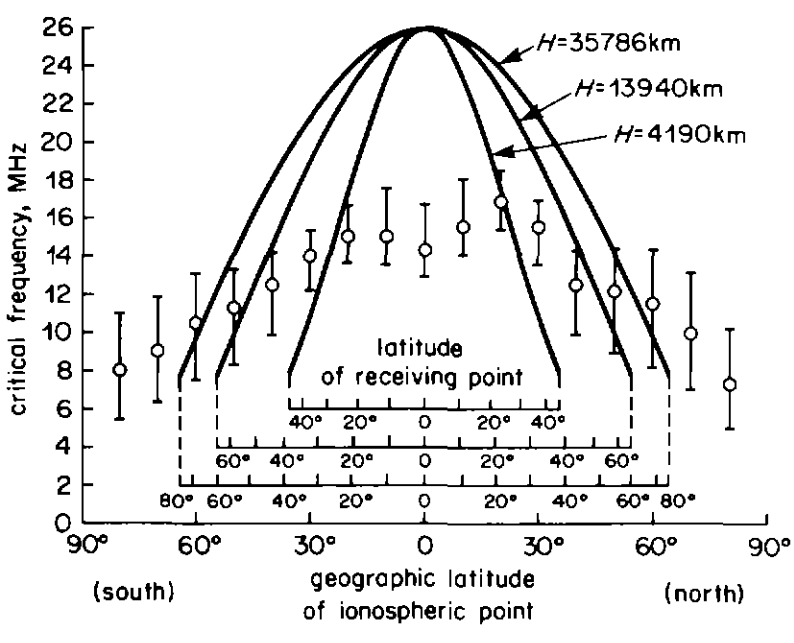

Fig. 2 - F2 layer daytime critical frequencies

(Smoothed sunspot number R_{12} = 100) The curves show values of 26 cos i calculated for satellites in equatorial orbits, and for the three values of H indicated.

describes the day-to-day variation about the monthly median values in terms of the upper and lower deciles.

Fig. 2 shows the greatest values of F2 layer critical frequency given by the maps of CCIR Report 340, for the smoothed sunspot number (R_{12}) of 100, at 10° intervals of geographic latitude. These values occur near noon. Also shown in Fig. 2 is the range between the upper and lower deciles, for the same time of day and the same sunspot number, calculated from the data given in Reference 4.

CCIR Report 340 also contains maps for times of low solar activity (R_{12} = 0) and these show critical frequencies which are about 4 MHz lower than those shown in Fig. 2. Report 340 also contains an extrapolation formula which gives critical frequencies which are 2 MHz higher than those shown in Fig. 2 when R_{12} = 150 and it recommends that values calculated for R_{12} = 150 should be assumed if the sunspot number exceeds 150. The smoothed sunspot number usually exceeds 100 at the peak of the solar cycle. During the 1954—1964 cycle, which was exceptional, it exceeded 100 for 4½ years and reached a maximum of 200.

To determine the extent to which 26 MHz waves would penetrate the F layer during the day, critical frequencies such as those shown in Fig. 2 must be compared with calculated values of 26 cos i; if the critical frequency in MHz is less than this quantity, penetration will occur. Fig. 2 therefore includes curves which give 26 cos i for satellites in equatorial orbits, and which are based on the assumption that the receiver point has approximately the same longitude as the satellite. In drawing these curves, 26 cos i was calculated for the ionospheric point A shown in Fig. 1 and plotted for the latitude of A. Consequently Fig. 2 shows what happens at the latitude of the ionospheric point, not at the latitude of the receiver, which is always greater. Auxiliary scales attached to each of the curves of Fig. 2, however, show the latitudes of the receiving points.

Fig. 2 shows that 26 MHz transmissions would penetrate the F2 layer at all latitudes up to 50° on 90% of the days when R_{12} = 100, if a geostationary (H = 35,786 km) satellite were used. Reception would then be possible up to latitudes of 55°, because of the extra distance traversed by the wave after passing through the layer. A satellite making two passes per day (H = 13,940 km) would provide a service up to latitudes of 45° but if a satellite at a height of 4,190 km were used, reception would be possible only up to latitudes of 20°.

The figures quoted in the last paragraph apply to receiving points on the same longitude as the satellite. The extent of reception on the equator can also be inferred from Fig. 2, which shows that the upper decile critical frequency above the equator is about 17 MHz when R_{12} = 100. This value lies below the curve for the geostationary satellite up to an angular distance of 43°; this is the longitude of the ionsopheric point where the wave will just penetrate the ionosphere. It follows, therefore, that continuous reception of a synchronous satellite would be possible between longitudes of 47° on either side of the sub-satellite point. Fig. 2 also shows that reception of a satellite making two passes per day (H = 13,940 km) would extend to longitudes of 35° on either side of the sub-satellite point. Reception at a given point on the equator would be possible for 2.3 hours during each pass and a two-hour programme could therefore be transmitted to a zone 10° wide twice each day. If a satellite at a height of 4,190 km were used, however, reception would be possible only between longitudes of 25° on either side of the sub-satellite point and transmissions to any given point on the equator would be limited to about 30 minutes at each pass because of the rapid satellite movement.

The ranges of latitudes and longitudes quoted above define a roughly elliptical area which would not be screened by the daytime F layer. When the sunspot number is less than 100 the unscreened area will be larger; conversely it will be smaller if the sunspot number exceeds 100.

2.2. Shielding by the sporadic-E layer

Unlike the F layer, the sporadic-E layer is thin and has steep refractive-index gradients. Consequently it reflects waves by partial reflection instead of by the more normal process of refraction. Incident waves are therefore partly transmitted and partly reflected. Equal power division between transmitted and reflected waves is a useful criterion to determine whether or not the layer can be regarded as transparent. The layer is therefore assumed here to be transparent if its transmission loss is less than 3 dB or if its reflection loss exceeds 3 dB.

Information about the transmitting properties of the sporadic-E layer can be derived from studies which have been made of the way it obscures the F layer when the latter is used for terrestrial h.f. communication. Knowledge of its reflecting

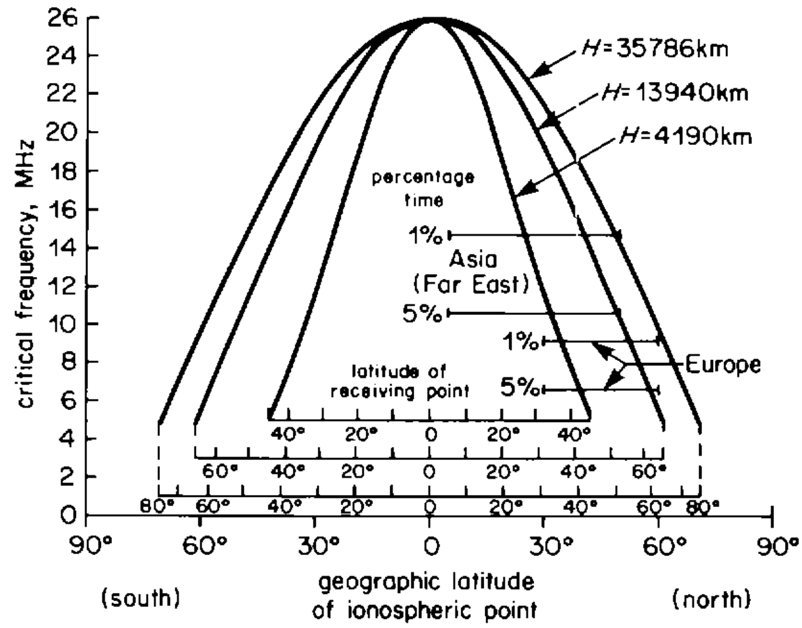

Fig. 3 - Sporadic-E layer critical frequencies

Summer daytime critical frequencies exceeded for stated percentage times

The curves show values of 26 cos i calculated for satellites in equatorial orbits

properties has been derived from observations of anomalous v.h.f. terrestrial propagation via the sporadic-E layer.

Studies of obscuration loss have shown that waves of frequency f will penetrate the sporadic-E layer with less than 3 dB of attenuation if the critical frequency foEs is less than $f \cos i$. The shielding effect of the sporadic-E layer may therefore be studied by the method described in Section 2.1, because penetration of the F layer is governed by the same criterion. Thus values of 26 cos i calculated for satellites in equatorial orbits are compared in Fig. 3 with values of foEs for the sporadic-E layer. The curves of Fig. 3 differ slightly from those of Fig. 2 because they are calculated for an ionospheric height of 110 km instead of 300 km. The critical frequencies shown in Fig. 3 were derived from Figs. 5 and 7 of CCIR Recommendation 534.[5] They show the values exceeded for 1% and 5% of the hours of daylight in summer, in Europe and in the far-eastern part of Asia, and they span the range of latitudes for the areas which they represent. Fig. 6 of Reference 5 shows that values for North America are similar to those for Europe. No values are shown for the southern hemisphere but Fig. 13 of Reference 5 suggests that critical frequencies are no higher south of the equator. Near the equator the sporadic-E layer is highly transparent at vertical incidence and has very little screening effect.[6] Since critical frequencies are highest during summer daytime, Fig. 3 applies to the time when shielding by the sporadic-E layer is most likely to occur.

The conclusion which may be drawn from Fig. 3 is that transmissions from a geostationary satellite (H = 35,786 km) would seldom, if ever, be screened by sporadic-E layers although some screening would be experienced by satellites in lower orbits.

3. Effects caused by traversal of the ionosphere

The effect of the ionosphere on satellite transmissions is described in CCIR Report 263-4.[7] The only effects which are important at 26 MHz are attenuation (due to non-deviative absorption), change of polarization and scintillation.

3.1. Absorption

Most of the absorption or attenuation occurs at a height of about 100 km. It varies in proportion to $(\sec i)/f^2$, where i is the angle of incidence at the absorbing region. According to Reference 7, absorption at mid-latitudes for a one-way traversal at vertical incidence at 30 MHz is typically only 0.2 to 0.5 dB. The absorption is greatest for waves arriving tangentially at the Earth's surface, when $\sec i = 5.8$ at a height of 100 km. It follows, therefore, that the absorption at low elevation angles under normal conditions at 26 MHz will be between 0.9 and 2.2 dB. An allowance of 3 dB has been made for ionospheric attenuation in Reference 2.

Enhanced absorption, which may last for periods up to about 30 minutes, may be caused by solar flares. The effect of a solar flare is greatest near the sub-solar point.[7] The absorption at vertical incidence at 30 MHz during a solar flare will be less than 5 dB; at oblique incidence at 26 MHz it could therefore be as much as 20 dB if a wave arriving tangentially at the Earth's surface passes through the ionosphere at the sub-solar point. This is possible in tropical regions if the satellite transmission is received on a longitude which is somewhat different from that of the satellite but cannot occur on the same longitude as the satellite because the waves could not arrive by a near-tangential passage through the ionosphere at a sub-solar point. Solar flares occur on average once every three or four days when solar activity is high.

3.2. Polarization

Assuming a linearly polarized transmitting antenna, the plane of polarization of an h.f. wave propagating through the ionosphere rotates about the direction of propagation as the wave progresses. A 100 MHz wave propagating through the ionosphere at an elevation angle of 30° would experience about 30 rotations.[7] Since the effect is inversely proportional to f^2, more than 400 rotations would occur at 26 MHz but the exact number of rotations would vary continuously, since it is proportional to the total ionization along the path. Consequently the signal received on a wire or ferrite-rod aerial would also vary and deep fades would be experienced.

This difficulty can be easily overcome by transmitting with circular polarization, with either sense of rotation. The wave polarization will still be almost circular after its passage through the ionosphere and polarization fading will not occur even if a simple aerial is used.

3.3. Scintillation

Local variations in electron concentration give rise to sporadic variations of amplitude which may be quote severe.[7] Scintillations are most likely to occur when the downcoming wave traverses either the equatorial or auroral ionosphere, but moderate scintillations are also observed in temperate latitudes. When scintillations are most severe, the amplitude distribution of the received signal approximates to the Rayleigh distribution,[7] with fading periods which may sometimes last for several minutes but which are often shorter and more typical of signals received by ionospheric reflection.

The occurrence of severe scintillation shows considerable seasonal, diurnal and latitude variation, but on average it occurs for at least 10% of the total time. If the signal exhibits a Rayleigh distribution during this period, then it will fade to more than 5 dB below its median value for about 2% of the total time.

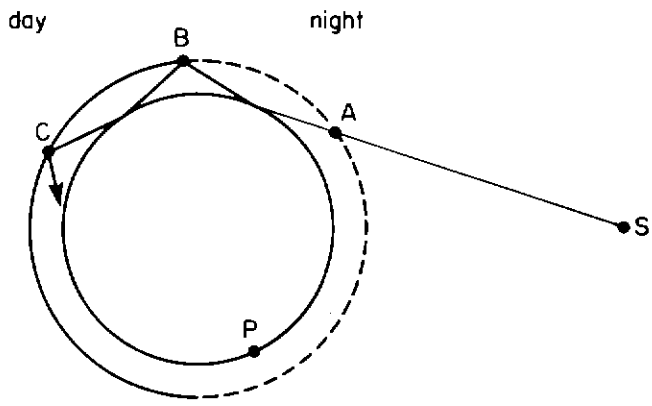

Fig. 4 - Propagation beyond the illuminated region

4. Propagation beyond the illuminated region

Under certain conditions, waves can propagate to parts of the Earth which are not directly visible from the satellite. This possibility is illustrated in Fig. 4, which shows how a wave from a satellite S might penetrate the night-time ionosphere at A but be reflected by the day-time ionosphere at B and C, thereby reaching the part of the Earth's surface which is not directly illuminated by the satellite. Here the signal might interfere with co-channel transmissions from satellites stationed on the other side of the Earth or with terrestrial services operating in the daylight zone.

Signals arriving almost tangentially at the Earth's surface are those most likely to cause interference on the other side of the Earth, because they propagate with fewer hops, and therefore with less loss, then those arriving at higher angles of incidence. They are also more likely to be reflected by the ionosphere because of their larger angles of incidence. A 26 MHz transmission reflected tangentially from the Earth's surface will be reflected by the F2 layer if the critical frequency of the layer exceeds 8 MHz; Fig. 2 shows that this condition is nearly always satisfied. It follows, therefore, that 26 MHz transmissions will nearly always propagate to the far side of the Earth if they are reflected tangentially from the Earth's surface near the day-to-night transition.

The possibility of round-the-world echoes has also been considered; these might interfere with the direct signal from the satellite and cause distortion. For example, a wave could propagate around the world to P (Fig. 4) and interfere with the direct transmission from S but it would be considerably attenuated because it would experience at least 5 ionospheric reflections over a daylight path. Much stronger round-the-world propagation can occur in terrestrial broadcasting, usually over a predominantly night-time path and at a lower frequency, because waves encounter a tilted ionosphere without intermediate ground reflection therefore with less attenuation.[8] Although waves could pass through the ionosphere near A (Fig. 4) and then propagate around the Earth without intermediate ground reflection, they are more likely to escape from the ionosphere near P than to be deflected towards the Earth's surface because the layer tilt is in the wrong direction for the wave to be deflected downwards.

5. Reception of 26 MHz transmissions

The strength of the received signal will be modified by ground reflection, while the quality of reception will depend on the intensity of radio noise. Both of these factors are considered in this section.

5.1. The effect of the ground

Simple receiving aerials respond either to an electric or a magnetic field component. Near the ground, the field strength of the downcoming wave is modified by ground reflection and the open-circuit voltage induced in a receiving aerial suffers the same modification as the field component to which it responds. Proximity to the ground also modifies the radiation resistance of an aerial but this has little or no effect on the power available from an aerial in a given field, because domestic receiving aerials have loss resistances which greatly exceed their radiation resistances. Thus the power available from a domestic receiving aerial depends only on the strength of the field component to which it responds. This may be compared with the strength of the downcoming wave, the ratio being referred to here as the signal gain. If the downcoming wave is circularly polarized, the reference field strength is taken as that of one of the two linearly-polarized waves which combine in phase quadrature to produce circular polarization.

Fig. 5(*a*) shows signal gains for short wire or metal rod aerials tilted at various angles. The wire is assumed to be less than 1m long, with its centroid* 1m above ground; this simulates a portable receiver on a table on the ground floor. Fig. 5(*a*) shows that the response of a vertical aerial would be poor when the satellite is directly overhead, as would be expected, but a horizontal aerial would give satisfactory results. Fig. 5(*a*) suggests that a suitably inclined wire aerial should have a signal gain of about 0 dB for all satellite elevation angles greater than 20°.

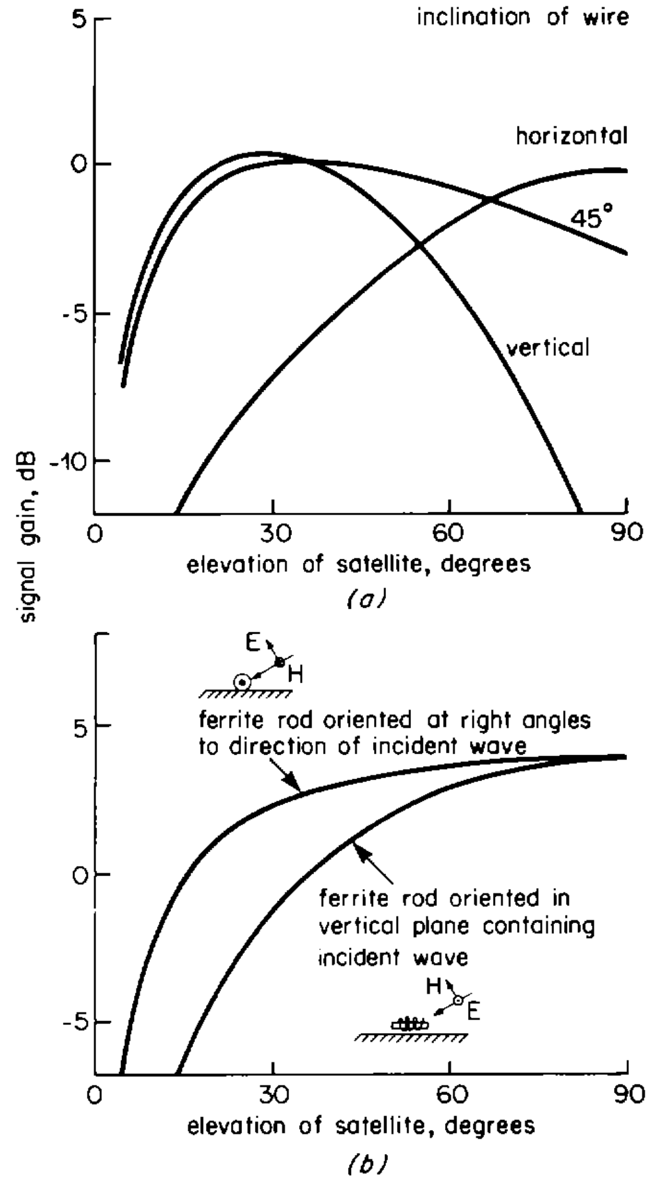

Fig. 5 - Signal gains of simple receiving aerials above imperfectly-conducting ground

(a) Short tilted wire 1m above ground

(b) Ferrite rod at ground level

Frequency 26 MHz Ground conductivity 10 mS/m

Dielectric constant 10

Ferrite-rod aerials are used for the lower frequency bands in some h.f. receivers and may be used in the future at 26 MHz. As they are not so

* The centroid of the current distribution if the aerial were driven. For an electrically short aerial the centroid is situated one-third of the length of the aerial away from the drive point.

directional in the vertical plane they would be more convenient to use for satellite reception than wire aerials. Fig. 5(*b*) shows that a ferrite-rod aerial oriented towards a satellite in the way that it would be oriented to receive a terrestrial transmission would have a signal gain of 1 to 3 dB at all elevation angles greater than 20°. Ferrite-rod aerials are at present much less efficient than wire aerials, however, and their use might not be advantageous for the reception of weak signals, which might be attenuated to a level at which the internal receiver noise becomes the dominant source of noise. Ferrite-rod aerials may become more attractive with future improvements in ferromagnetic materials.

5.2. Radio noise

There are three kinds of radio noise: atmospheric, galactic and man-made. Galactic noise, which is of extra-terrestrial origin, has been measured with horizontal dipoles $\lambda/4$ above ground.[9] Thus the published figures for galactic noise can be applied without correction to the reception of satellite transmissions. According to CCIR data,[10,11] the upper limit of galactic noise at 26 MHz is 20 dB above thermal noise.

Atmospheric noise varies with time of day, season and geographic location. According to Reference 10, it seldom exceeds galactic noise at 26 MHz and can therefore be disregarded. Man-made noise, however, may rise to 37 dB above thermal noise in city centres, or to 30 dB above thermal in more rural environments.[11] Man-made noise is believed to propagate mainly by ground wave and is measured on short vertical aerials. Fig. 5 shows that the use of other types of aerial is unlikely to increase the level of man-made noise in the receiver.

The conclusion, therefore, is that man-made noise predominates. For planning purposes it will be assumed here that its average value is 30 dB above thermal noise. With a 10 kHz bandwidth the power available from a short vertical loss-free aerial would be -134(W); it is reasonable to assume that this figure applies equally to all the receiving aerials described in Section 5.1.

6. System examples

Table 1 gives estimated power budgets, first of all for a geostationary satellite using conventional amplitude modulation (a.m.) and then for cases in which the satellite power might be reduced by (a) the use of relatively narrow-band frequency modulation (f.m.), or (b) the use of a satellite with an 8-hour period, making two passes a day. The examples have been chosen to give an unweighted signal-to-noise ratio of 33 dB with an audio bandwidth of 5 kHz.

The f.m. system assumed uses ±5 kHz deviation and a small improvement of 2.5 dB in signal-to-noise ratio would be achieved by the use of 75μs of pre-emphasis. This system would give 7 dB advantage over a.m. but would require 20 kHz rather than 10 kHz channel width. Since special receivers would be required, the use of ferrite-rod receiving aerials has been considered. However, a ferrite rod would offer no performance advantage over a wire aerial at present because it would attenuate both the signal and received noise by some 30 to 35 dB, and this would degrade the audio signal-to-noise ratio by up to 9 dB. With future improvements, however, the degradation might be reduced to 2 dB relative to an open wire aerial.

As indicated in Section 3.2, the transmission would have to be circularly polarized in order to avoid signal fading arising from double refraction. A transmitting array of up to 20 dB gain might be most economically constructed from an array of 4 or 7 helical arrays or possibly crossed Yagi arrays, rather than a unit employing a parabolic reflector of some 45m diameter. Of course, in all designs, unfolding in space from a compact unit is necessary. The satellite antenna gain given in Table 1 is the net gain after allowing for 1 dB coupling and feeder losses; the 'efficiency factor' correction for parabolic reflectors does not apply.

For the sub-synchronous satellite, a non-retrograde circular equatorial orbit is assumed and, if it has an altitude of 13,940 km, it will orbit with an 8-hour period and pass over a given point on the equator every 12 hours. In this case a single satellite could be used to give to various areas in turn a series of programmes of limited duration (say 30 mins or 1 hour) at the same time every day, in the morning and afternoon/evening. A single sub-synchronous satellite is unsuitable for maintaining a continuous service to any given area, but a series of sub-synchronous satellites could be used for this purpose. It would be necessary to employ at least four satellites (at 90-degree separation) in orbit to maintain a continuous service to areas near the equator. For medium latitudes more satellites would be needed for a reliable service.

TABLE 1

Examples of Power Budget for 26 MHz Sound Broadcasting from a Satellite

Orbit	24-hour	24-hour	8-hour
Altitude of satellite, Mm	35.8	35.8	13.9
Modulation system	a.m.	f.m.	a.m.
Transmitter power, kW dB(W)	5 37	1 30	1.5 32
Satellite aerial gain (rel. isotropic source) dB	20	20	17
E.i.r.p., dB(W)	57	50	49
Propagation loss(1) exceeded 2% of total time, dB	7	7	7
Free-space attenuation	151	151	143
Polarization coupling loss, dB(2)	3	3	3
Flux at ground, dB(W/m^2),	−115	−112	−115
Field strength, dB(μV/m)	31	24	31
Type of aerial	wire	wire	wire
Receiving aerial gain, dB(3) (rel. to isotropic aerial)	2	2	2
Received signal power dB(W)	−101	−108	−101
Noise bandwidth, kHz	10	20	10
System noise factor,(4) dB	30	30	30
Noise power, dB(W)	−134	−131	−134
Carrier-to-noise ratio, dB	33	23	33
Audio signal-to-noise ratio, in 5 kHz, dB	33	33	33

(1) Loss includes 2 dB of ionospheric attenuation and 5 dB of scintillation loss, exceeded for 2% of total time.

(2) Assumes polarization to be circular for transmitter and linear for receiver.

(3) Gain of simple aerial relative to isotropic aerial (2 dB) plus signal gain given by Fig. 5(*a*) (typically 0 dB).

(4) Figure for semi-rural environments – See Section 5.2.

7. Conclusions

26 MHz transmissions from satellites can be received reliably (apart from occasional solar-flare attenuation) and with negligible distortion throughout the day and night in zones near the sub-satellite point, but ionospheric effects reduce the reliability for higher latitudes, and at other longitudes relative to the satellite, particularly for daytime reception. For a geostationary satellite, there would be good reliability within a circle centred on the sub-satellite point and passing through points approximately 50°N, S, E or W of the point. Signals can also reach the side of the Earth away from the satellite and could interfere with other satellite or terrestrial transmissions on the same channel.

The ionosphere has a considerable effect on the polarization of 26 MHz waves passing through it. Fading caused by polarization changes can be completely eliminated by transmitting with circular polarization and this is an essential requirement.

If a geostationary satellite were used, a 33 dB signal-to-noise ratio could be achieved using a conventional h.f. receiver with a tilted whip aerial and a 5 kHz bandwidth, with a transmitter power of 5 kW. The same result could be achieved with a transmitter power of 1.5 kW if a satellite in an 8-hour orbit were used. A single satellite in this orbit would make two passes per day and would be suitable if 30 minute to 1 hour morning and evening transmissions were required to be received in a given area. Alternatively an audio signal-to-noise ratio of 33 dB could be achieved by a geostationary satellite radiating 1 kW if narrow-band f.m. were used instead of conventional a.m. transmission.

8. References

1. PHILLIPS, G.J. *and* KNIGHT, P. 1978. Use of the 26 MHz band for satellite broadcasting. EBU Review, Technical, No. 170, pp. 2 – 7, (1978).

2. Broadcasting satellite service: sound and television. CCIR Report 215-4 (1978).

3. Atlas of ionospheric characteristics. CCIR Report 340 (published in a separate volume, 1966).

4. Second CCIR computer-based interim method for estimating sky-wave field strength and transmission loss at frequencies between 2 and 30 MHz. CCIR Report 252-2 (published in a separate volume, 1970).

5. Method for calculating sporadic-E signal strength. CCIR Recommendation 534 (1978).

6. VHF propagation by regular layers, sporadic-E or other anomalous ionisation. CCIR Report 259-4 (1978).

7. Ionospheric effects upon earth-space propagation. CCIR Report 263-4 (1978).

8. Long-distance ionospheric propagation without intermediate ground reflection. CCIR Report 250-4 (1978).

9. COTTONY, H.V. *and* JOHLER, J.R. 1951. Cosmic radio noise intensities in the VHF band. *Proc. IRE,* **40**, pp. 1053 – 1060, (1952).

10. World distribution and characteristics of atmospheric radio noise. CCIR Report 322 (published in a separate volume, 1963).

11. Man-made radio noise. CCIR Report 258-3 (1978)

SMW/AM

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