RECOMMENDATION ITU-R BT.1123*

Planning methods for 625-line terrestrial television in VHF/UHF bands

(1994)

The ITU Radiocommunication Assembly,

considering

a) that broadcasting transmitter networks should be planned in such a way that the required coverage of the area is provided using the minimum number of frequencies;

b) that the theory of uniform transmitter networks is useful for designing new transmitter networks or remodelling existing ones;

c) that while well-established networks exist, there is still a need for guidance on planning methods for new 625-line systems,

recommends

1 that the methods set out in Annexes 1 and 2 be used for the design of transmitter networks for the preliminary planning of new 625-line terrestrial television networks in the VHF/UHF bands.

ANNEX 1

Planning methods for terrestrial television in VHF/UHF bands

1 General

Broadcasting-transmitter networks should be planned in such a way that the required coverage of the area is provided using the minimum number of frequencies. The coverage area of each transmitter depends upon a number of technical factors, for example: transmitter power, minimum usable field-strength, radio-frequency protection ratio, the distance between transmitters sharing the same or adjacent channels, channel spacing, bandwidth of emission and factors influencing wave propagation. It may also depend on the channel distribution scheme.

When a large number of channels is to be planned or replanned for a particular AM or FM sound or television service, it has been found that utilizing the spectrum efficiently can prove difficult when only empirical methods are employed. For this reason, a theory of uniform transmitter networks was developed.

This method can be applied with success when some uniformity of standards exists for the services to be planned. Furthermore, the frequency band to be planned should be constrained as little as possible, i.e. there should ideally be complete freedom in assigning any frequency to any transmitter.

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* Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2002 in accordance with Resolution ITU-R 44.

This theory is not only useful in designing new transmitter networks or remodelling existing ones, but also provides a powerful tool for determining optimal technical parameters such as channel spacing, transmitter characteristics, etc., and identifying the best attainable coverage.

Some countries may prefer to have a complete area coverage with a small number of programmes and others to sacrifice total area coverage in favour of providing more programmes in the more highly populated areas. In these cases, uniform network theory can be used to provide some reference values for attainable coverage. This can help when comparing the differing networks of individual countries which have chosen different methods for achieving their internal coverage.

This Annex refers only to 625-line systems. The attention of administrations using other systems is drawn to this fact. Additional data concerning all systems are required.

2 Theoretical techniques for an international plan

2.1 General

Planning techniques resulting from the principle of uniform transmitter networks may be considered to comprise two basic elements:

- geometrically regular lattices,
- linear channel-distribution schemes.

Because of the many parameters and effects that may have an impact on frequency planning, e.g. varying propagation conditions, transmitter powers, transmitting-antenna heights and directivities, and terrain irregularities, the problem first requires simplification by assuming all transmitters to have equal powers, to have omnidirectional antennas all at the same height and with the same polarization, and to be situated on an infinitely extended area forming a geometrically regular lattice; also that propagation conditions do not exhibit variations throughout the area considered.

The development of such regular lattices is discussed in some detail in Appendix 1 and leads to the following basic conclusions:

- full area coverage can most economically be provided by a lattice having equilateral elementary triangles i.e. having equally spaced geographically adjacent transmitters. Some overlap coverage is inevitable if complete area coverage is to be achieved. This can be expressed in terms of a “coverage factor” i.e. the sum of individual coverage/total area to be covered. The reciprocal of the coverage factor is often referred to as the coverage efficiency. This coverage factor has a minimum value of 1.21 for the optimum case of equilateral elementary triangles;
- because, for television broadcasting, the required co-channel protection ratio predominates over those for other frequency spacings by a large amount, optimum coverage is also likely to be achieved by maximizing the spacing of co-channel transmitters, i.e. by ensuring equilateral co-channel triangles;

- only particular numbers of channels allow both co-channel and elementary triangles to be equilateral. These are known as “rhombic numbers” and require that the number of channels, C, is such that:

$$C = a^2 + ab + b^2$$

where a and b are non-zero integers and without a common divisor.

For values of $C < 80$, these numbers are given by:

a	1	2	3	3	4	4	5	5	5	5	6	7	7	7	8
b	1	1	1	2	1	3	1	2	3	4	1	1	2	3	1
C	3	7	13	19	21	37	31	39	49	61	43	57	67	79	73

If, however, the total spectrum available for the network does not correspond to a number of channels coincident with a “rhombic number”, a solution using the full available number of channels will still be possible but this will generally mean adopting a lattice formation in which either the co-channel or elementary triangles will not be equilateral. Such a solution may well permit substantially better coverage than that obtainable by restricting spectrum usage to that corresponding to the next lower rhombic number. Exceptionally, other channel numbers can also permit both equilateral elementary and co-channel triangles but in such cases linear channel distributions (see Annex 1, § 3) cannot be used and hence interference levels are not necessarily uniform through the lattice. An example of such a network is given in Fig. 14.

If it is considered more important to have the elementary triangles equilateral, this may be achieved by a transformation (e.g. affine) which retains the longest side and rotates and extends the remaining sides to make them equal. An example of such a transformation for an 8-channel lattice is indicated in Fig. 3b).

Having once established lattices of the type described above, the problem is then to arrange the channels required in such a way as to minimize interference, remembering that every co-channel rhombus forms only part of a lattice extending over the whole planning area. The derivation of linear distribution schemes is discussed in some detail in Appendix 1.

Such a linear distribution has the property of having an identical interference situation on all channels, except for those on the highest and lowest frequencies (in cases where adjacent-channel interference is relevant).

The method can be extended to the case (an example of this is given in § 2.6) where it is desired to provide n programmes from each site using a total of nC channels in contiguous sub-bands each of C channels. In this case the channels assigned to each transmitter will be:

$$c, c + C, c + 2C, \text{etc.,} \quad \text{where } 0 \le c \le C - 1$$

2.2 Implications of applying regular lattice planning principles in specific terrestrial television bands

In the following sections, the application of these principles to the specific numbers of channels available in each band will be considered, and at the same time these examples will be used to develop further aspects of these planning principles.

However, before considering the implications in individual bands, it is appropriate to consider which frequency relationships, additional to co-channel, need to be taken into account in television network planning (see Annex 2).

These are:

Frequency relationship	Channel difference
Adjacent channel	1
Radiation from local oscillator(1)	4 or 5
Image channel(1)	8, 9 or 10

(1) For channel spacings and receiver intermediate frequencies in general use.

For any lattice based on approximately equilateral elementary triangles, it follows that any transmitter will be spaced almost equidistantly from six other transmitters which, except in the case of lattices with a very small number of channels, will all be on different channels. It follows therefore that unless very distorted elementary triangles are adopted, no lattice having less than eight channels can avoid having adjacent-channel overlaps. Figure 2b) shows an example of a 7-channel lattice which avoids adjacent-channel overlaps at the cost of distorting the elementary triangles hence requiring a substantial increase in the coverage radius required of individual transmitters.

2.3 Band I

The full extent of this band is 21 MHz. Hence, the maximum number of channels available is three for any transmission system currently in use having 7 MHz bandwidth. Only one form of lattice is possible with three channels, which has the following characteristics:

a) the three channels are at the apexes of the elementary triangles;

b) equilateral elementary and co-channel triangles (three is a rhombic number);

c) co-channel spacing = $\sqrt{3}$ times the spacing between adjacent transmitters;

d) for complete coverage, the maximum distance between any transmitter and the nearest point on the coverage area of the next co-channel transmitter (at the centroid of the elementary triangle) is twice the coverage radius.

The implication of a) is that adjacent-channel overlaps are inevitable.

The implication of d) is that complete area coverage is only possible (even if any allowance for multiple interference or interference from other than co-channel transmitters is neglected), when the field strength at the extremity of the coverage radius exceeds that at twice the distance by at least the value of the required co-channel protection ratio.

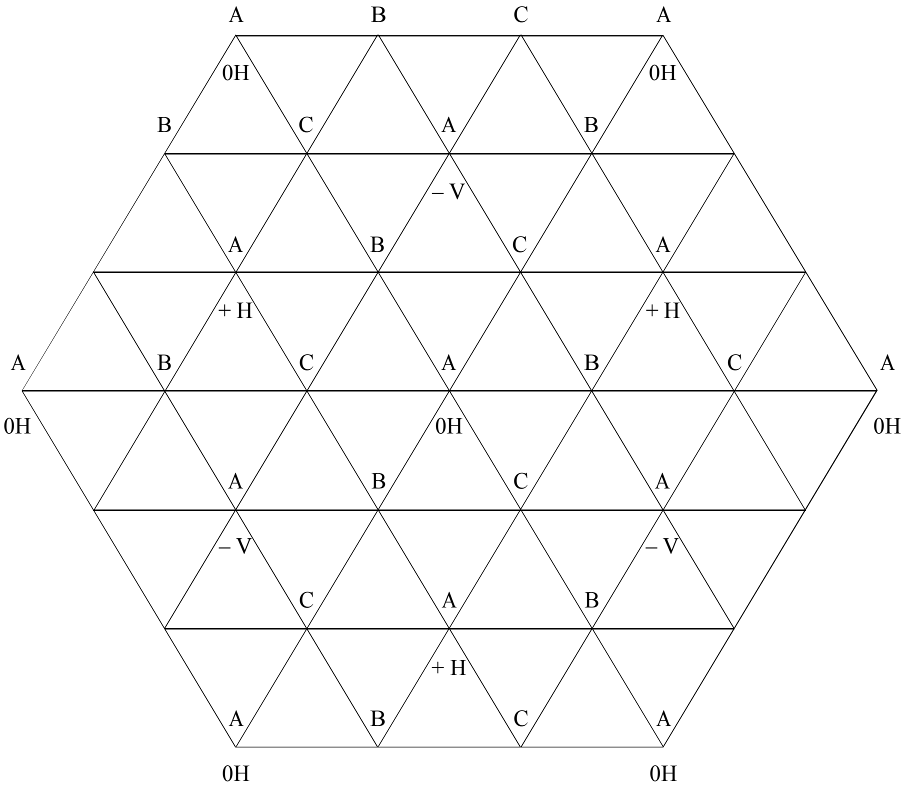
Figure 1 shows, taking a three-channel lattice as an example, how a systematic use of frequency offsets and use of both horizontal and vertical polarization can reduce co-channel interference. In the general case, polarization discrimination can also be used to reduce adjacent-channel interference. However, in the particular case of three channels (as shown in Fig. 1), this is of limited advantage since the middle channel (B) is equidistant from two of each adjacent channels and polarization discrimination could only be obtained against one of each pair. The same principles, can of course, be applied to any lattice. It may be seen that:

- the separation distance between co-channel transmitters without either polarization or offset protection is now three times that between adjacent channel transmitters;

- all of the nearest ring of six co-channel transmitters have offsets but only three also have the opposite polarization (this is because while three offset options are possible, there are only two polarizations).

FIGURE 1

3-channel lattice demonstrating use of frequency offsets and polarization to reduce interference



A, B, C: channels
H, V: polarizations
0, +, –: offsets (1/3 line time-base)

Offsets and polarizations shown for channel A only.

In view of the high values of co-channel protection required for a television service, even taking account of the reduction in interference possible by frequency offset and polarization discrimination, full area coverage cannot be provided by a three-channel lattice, i.e. it is not possible to provide complete coverage over an extended area using Band I alone.

2.4 Band III

The total available spectrum is 56 MHz, permitting either 7 channels of 8 MHz channel width or *vice versa*. Whereas television systems using both 7 and 8 MHz nominal bandwidth are in use in ITU Region 1, it should be noted that in the UHF television bands a channelling of 8 MHz has been adopted throughout the Region. It would seem therefore that in any future planning this standard should also be adopted uniformly. Moreover, adoption of 8 MHz channelling would not preclude retention of television systems requiring 7 MHz nominal bandwidth if desired. However, for completeness, the following discussion examines both 7- and 8-channel lattices.

2.4.1 Seven-channel lattice

Superficially, the most appropriate lattice is that indicated in Fig. 2a) which has equilateral elementary and co-channel triangles (possible because 7 is a "rhombic number").

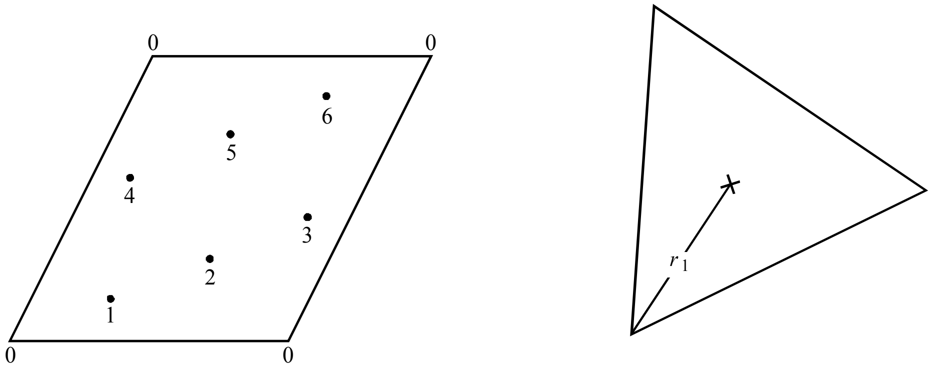
The lattice has the following characteristics:

- overlaps between adjacent channels;
- a co-channel distance of $\sqrt{7}$ times the distance between geographically adjacent transmitters. (The ratio of co-channel distance to the distance between transmitters is $\sqrt{No.\ of\ channels}$. This is an intrinsic characteristic of such a lattice.)

An alternative form of 7-channel lattice is that shown in Fig. 2b). The preference for this lattice is based on the greater adjacent-channel distances but, as indicated by Figs. 2c) and 2d), this is obtained at the cost of a considerable distortion to the elementary triangles and consequently a need for a 22% greater coverage radius by individual transmitters to achieve complete area coverage.

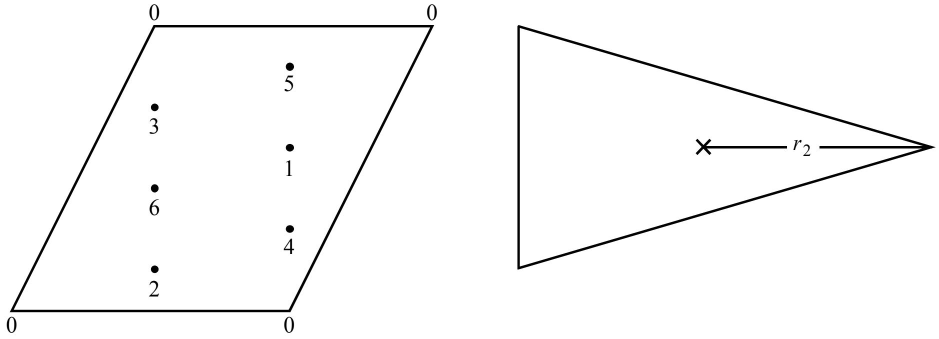
FIGURE 2

Examples of 7-channel lattices



a) Equilateral elementary triangles

c) Elementary triangle from a)
r_1: minimum radius for complete coverage



b) Avoiding adjacent channel overlaps

d) Elementary triangle from b)
r_2: minimum radius for complete coverage
Ratio $r_2/r_1 = 1.22$

Note 1 – Figures c) and d) are scaled to same co-channel distance.

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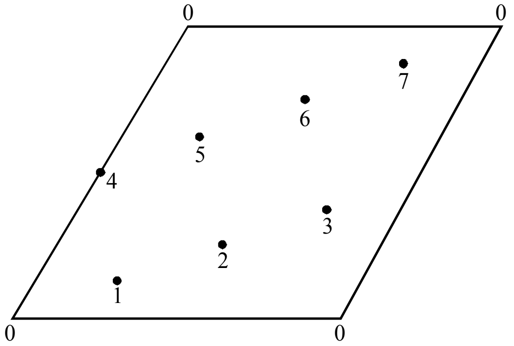
2.4.2 Eight-channel lattice

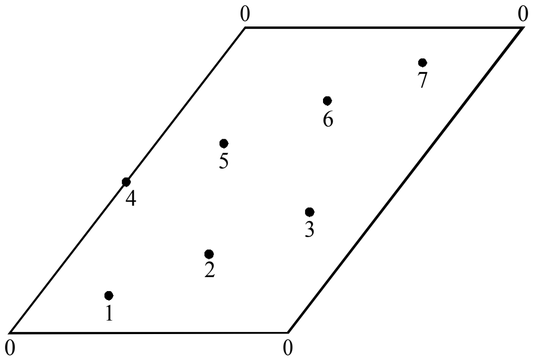
Not being a rhombic number, it is not possible to construct a linear channel distribution with both equilateral elementary and co-channel triangles. The lattice most closely approximating to this is that shown in Fig. 3a) (equilateral co-channel) and Fig. 3b) (normalized to give equilateral elementary triangles). Figure 3c) indicates an alternative lattice having more distorted elementary triangles for which the smallest distance between transmitters is not equal to that between adjacent channels. This does not, however, preclude some adjacent-channel overlap if full area coverage is to be achieved.

FIGURE 3

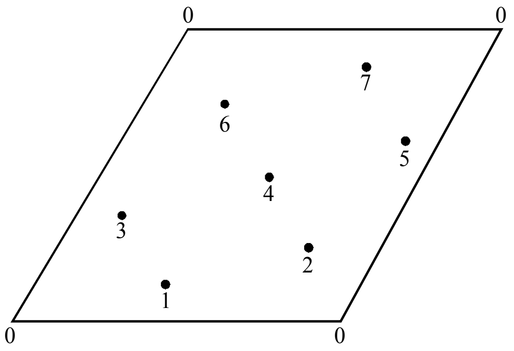
Examples of 8-channel lattices



a) Nearest approximation to equilateral elementary triangles



b) Lattice a) transformation to give equilateral elementary triangles



c) Alternative to reduce importance of adjacent-channel interference

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2.5 General comments on planning in VHF television bands

As previously mentioned, it is not possible to produce full coverage over an extended area with the three channels available in Band I. Such a single coverage can, however, be expected with the seven or eight channels available in Band III, but this band cannot generally provide two coverages. In any case, the extent of sporadic-E propagation in the lower Band I channels causes severe restrictions on the percentage of time for which a service may be achieved.

In principle, it would be possible to use both Bands I and III together in a coordinated manner to provide a high degree of area coverage with two programmes, i.e. using five channels for each programme. However, this implies adoption of a 7-MHz channelling system in at least one of the bands.

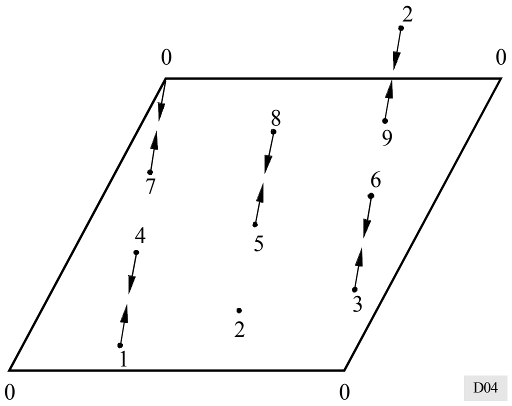
This also presents the following problems:

- while it is logical to use two of the three Band I channels together to ensure equal coverages, this may present engineering problems at the transmitter site;
- the third (presumably middle) Band I channel would in any event have to be used in conjunction with a Band III channel, thereby increasing antenna costs at both transmitting and receiving terminals and presenting problems in achieving equal coverages;
- the principles of linear lattice planning, as previously described, cannot be applied to such a composite network in view of the different propagation characteristics and non-continuous channelling.

Nevertheless, it is possible to envisage the use of a combined Band I and III two-programme network based on a 10-channel lattice such as indicated in Fig. 4 with the channels paired as shown. It will be appreciated that for such a pairing then, if channels 0-2 are in Band I, each Band I channel is paired with one in Band III. To keep two Band I channels together, the positions of channels 2 and 7 and of channels 3 and 9 could be transposed. As this particular lattice has 2-channel spacings on one side of each elementary triangle, it might be thought that pairings could be made along this axis. However, it is not possible to produce complete pairings of alternative numbers in a consecutive sequence unless the total is divisible by four.

FIGURE 4

10-channel lattice indicating "pairings" to provide two programmes



2.6 The UHF band

Although the UHF band consists of Bands IV and V, it is convenient for planning purposes to consider these as a single entity. With all of the channels in the two bands (even though all may not be fully available for broadcasting) it is clear that multiple coverages can be provided.

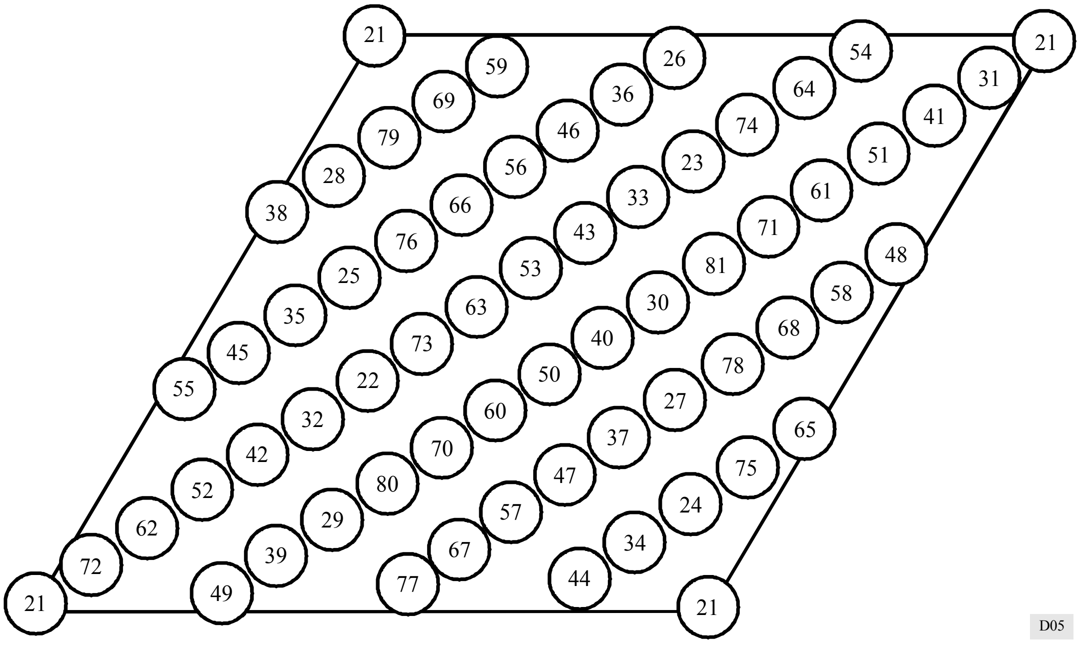
The concept of subdividing the total band into sub-bands allocated to individual coverages/programmes presents problems in the UHF television band because it would imply a wide range of spectrum usage in each coverage area. This in turn produces engineering difficulties due to the large bandwidth required of both transmitting and receiving antennas.

Because different countries in the overall planning area may have differing requirements, it may be more convenient to base planning on the use of a single lattice designed so as to enable frequencies to be "grouped" together in different ways.

The lattice used at the European Broadcasting Conference is represented in Fig. 5 and that for the African Broadcasting Conference in Fig. 6. Both have as a common feature, frequency separations of three channels between adjacent transmitters in one direction through the lattice. This permits easy "grouping" for three programmes using channels n, $n + 3$, $n + 6$.

FIGURE 5

Theoretical apportionment of channels in Bands IV and V, adopted by the European Broadcasting Conference (Stockholm, 1961)



Extension to four programmes by adding ($n + 9$) would not be appropriate, firstly because this represents a large spread in one dimension of the lattice, and secondly because of the risk of image channel interference between channels n and $n + 9$. However, the lattice adopted at the 1961 Stockholm Conference also has 10 channel spacings between adjacent transmitters in another direction through the lattice, enabling groupings to be made either of n, $n + 3$, $n + 6$, $n + 10$ (see Note 1) or n, $n + 3$, $n + 6$, $n + 13$. Of these, the former is preferable in respect of total spread of spectrum, the latter preferable in respect of the location spread within the lattice configuration. Without further extension of the location spread within the lattice, it is possible to envisage further extensions of this “grouping” principle within the “European” lattice to provide:

– five programmes using: n, $n + 3$, $n + 7$, $n + 10$, $n + 13$;

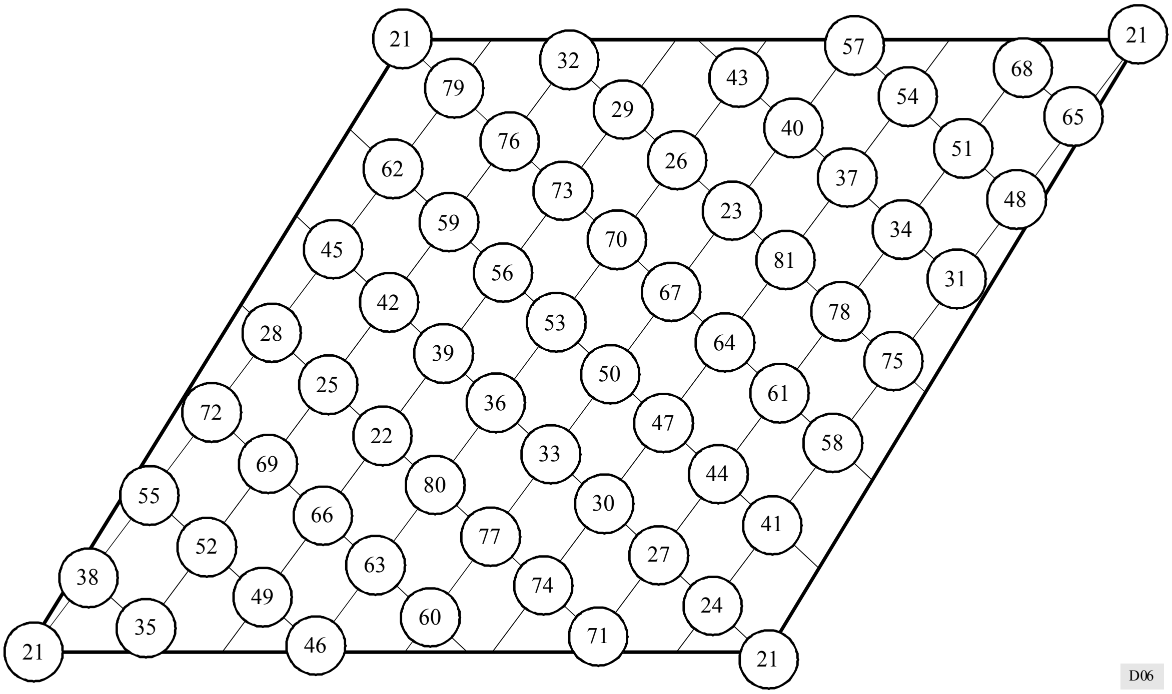
– six programmes using: n, $n + 3$, $n + 6$, $n + 10$, $n + 13$, $n + 16$.

NOTE 1 – Or, as a symmetrical alternative, n, $n + 4$, $n + 7$, $n + 10$.

The lattice adopted at the 1963 African Conference appears less amenable to extension of “groupings” above three programmes without unduly large spectrum spread or the introduction of an image channel relationship, n and $n + 9$, at the same transmitter site.

FIGURE 6

Bands IV and V – theoretical lattice adopted by the African Broadcasting Conference (Geneva, 1963)



3 Frequency offset plan

3.1 General

Optimum application of a lattice, as illustrated in Figs. 5 and 6, and described in Appendix 1 with respect to linear channel distribution, does not depend solely on the nominal frequency of an assigned channel. An excellent tool for ensuring better use of television broadcasting frequency bands is the possibility of assigning a suitable offset to the channels, thereby optimizing the protection between transmitters using the same channel (see Recommendation ITU-R BT.655). The optimum co-channel spacing can then be calculated by means of these offsets and used as the basis for the co-channel lattice.

3.2 Non-precision offset

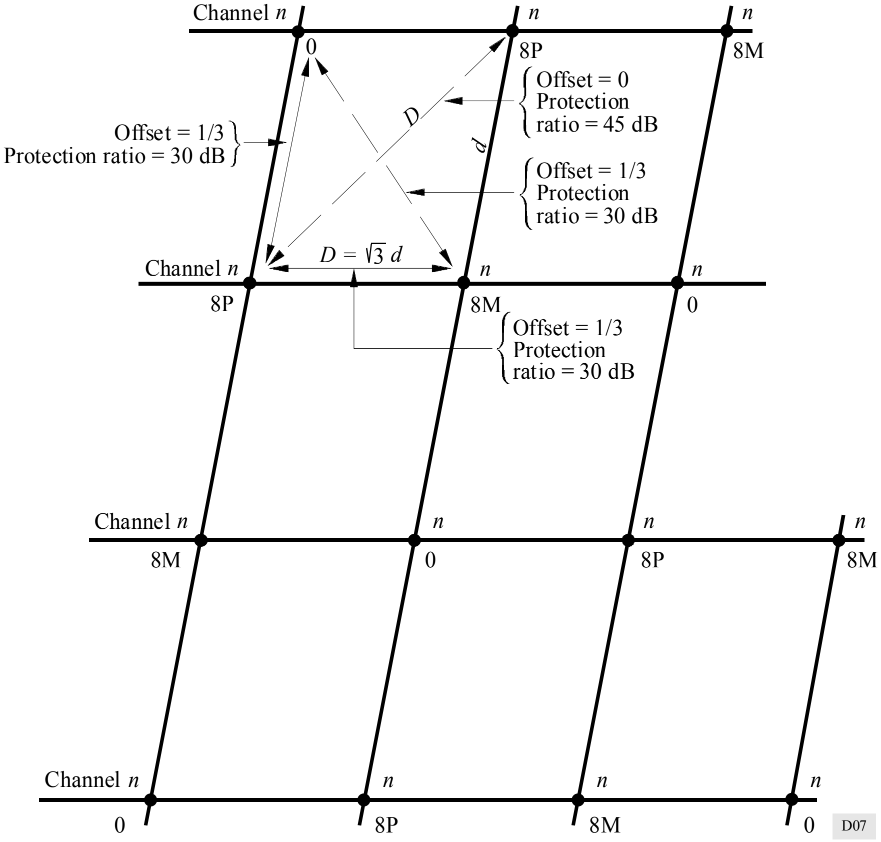
Optimum spacing between co-channel transmitters is obtained by specifying offsets providing the same protection between all transmitters in a co-channel lattice, namely 8M, 0 and 8P (offset by multiples of a third of the line frequency; protection ratio of 30 dB throughout, tropospheric interference), alternately allocated to the transmitter triplets of the half-lattices (see Fig. 7). The transmitters along the long diagonal are the only ones to have a relative offset of 0 and are therefore less well protected (protection ratio of 45 dB). However, this is compensated by the fact that the co-channel spacing between the transmitter pair is 1.73 times that of the transmitter triplets with an effective 1/3-line offset.

3.3 Precision offset

A further improvement in the efficiency of spectrum utilization can be achieved by using precision offset. However, the possibilities are limited if the network planning is based on a co-channel lattice as the transmitters along the long diagonal, which have a relative offset of 0, can only be operated with a non-precision offset and the co-channel spacing in the lattice is determined by this required minimum spacing.

FIGURE 7

Frequency offset distribution in a co-channel lattice (frequency offset plan)



3.4 Offset distribution in precision offset operation

Apart from the protection ratios for vision signals, Recommendation ITU-R BT.655 also specifies the protection ratios for the accompanying analogue sound. In the common offset distributions (8M, 0, 8P) of television channels there is a difference of approximately 10 kHz between the sound carriers of adjacent co-channel transmitters, resulting in a required protection ratio of 31 dB.

In the case of precision offset, a protection ratio of only 22 dB is required for the vision signals. To obtain the same protection ratio for the sound signals, it is necessary to adjust the offset by several multiples of the line frequency. The difference in the frequency of the sound signals has to be approximately 50 kHz to obtain a protection ratio of 22 dB (equal to that of the vision signals). The protection ratios of the vision signals are not changed provided that these signals are not offset relative to each other by more than three times the line frequency.

4 Capacity of the TV bands

4.1 Capacity of the VHF bands

As previously discussed, Band I can, at most, provide three channels and this only if a 7 MHz channelling system is adopted. Unless used for purposes not requiring complete area coverage, this band can therefore only be considered as a supplement to Band III.

The combined VHF band can provide 9 channels, if a transmission system requiring 8 MHz channelling is used and either 10 or 11 channels for a system requiring only 7 MHz channelling. In the former case, it would be unrealistic to consider providing coverage of more than a single programme using VHF only, but with 10 channels there is an option of providing two programmes with fairly high, although probably not total, area coverage. In such a case, it would seem desirable to attempt to minimize interference as much as possible by systematic use of both horizontal and vertical polarization.

It must also be remembered that in a practical situation the simplifications introduced into the theory (see § 2.1) will not generally apply. One result is that more channels will be needed for a given degree of coverage than the theory suggests. Other problems are mentioned in § 2.5.

Any form of composite Band I/Band III coverage will entail additional costs for the broadcasting authority because of the need for separate transmitting antennas. The use of log-periodic receiving antennas may avoid this requirement for the viewer, provided that both services use the same polarization in individual areas, although such an antenna would be physically rather large.

A further option to be considered if two programmes are to be provided at VHF is to complete coverage by means of UHF relays. This may well be practicable in countries where it is not intended to provide more than three programmes within the UHF band.

4.2 Capacity of the UHF bands

Experience gained in Europe may be used to estimate the capacity of the UHF bands in a practical case. It has to be noted that a maximum of only 48 channels (21 to 68) is available and that there is a gap of up to 5 channels between Bands IV and V which is unavailable for broadcasting in parts of Europe. However, it has generally been found possible to achieve three programme coverage with protection against interference for 99% of the time. In some cases, for example in the United Kingdom, the time for which protection is achieved has been reduced to 95% and it has then been found possible to achieve four programme coverage.

In any case, it is necessary to consider whether area coverage or population coverage is being sought. If the population distribution is fairly uniform, there may be little difference between the two concepts. However, if much of the population is concentrated into urban areas, there can be a large difference. In this case, it may be possible to achieve coverage of the urban areas with larger number of programmes than would be the case if a more uniform coverage had been the aim.

5 Assessment of planned coverage

In either the VHF or UHF bands, it is desirable to relate predicted or measured field-strength values to the satisfaction of television viewers with the quality of their received vision and sound signals. If this is to be done, it is important that the distribution of measurement locations should be heavily influenced by the population density. It is also necessary to consider the extent to which non-standard receiving installations may be used by viewers. The use of high-gain antennas or low-noise pre-amplifiers in areas of low population density permits an extension of the coverage achieved by a transmitter without requiring an increase in the field-strength values provided.

APPENDIX 1

TO ANNEX 1

Lattice planning: basic principles for the development of geometrically regular lattices having linear channel distributions

1 Basic assumptions

It is assumed that all transmitters:

- have the same powers, effective antenna heights and polarization and are all non-directional; and
- are situated on an infinitely extended area having uniform propagation characteristics.

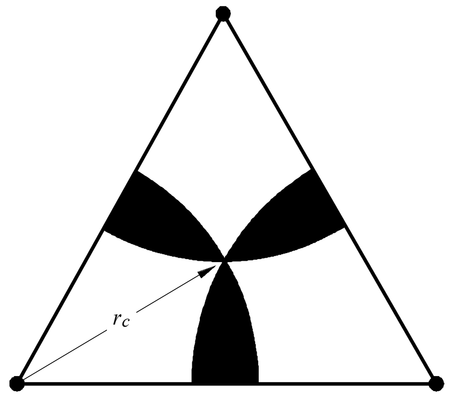
2 Geometrically regular lattices

Transmitters are considered to be situated at the points of intersection of two sets of parallels, each equidistant and covering the whole area. These two sets of parallels subdivide the area into parallelograms each corresponding to one intersection point, i.e. to one transmitter site. Hence complete coverage would be obtained if each transmitter uniquely provided coverage of an area equal in size (although almost certainly not in shape) to the parallelogram.

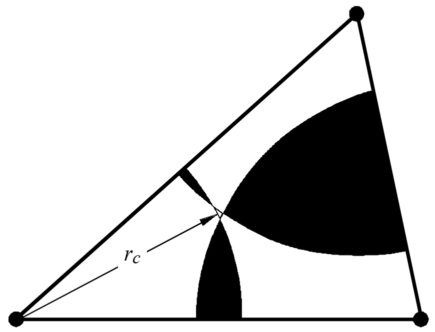
For convenience, a third set of parallels may be considered to be drawn through the intersection points, thereby dividing each parallelogram into two equal triangles. Assuming non-directional transmitting antennas and hence circular coverage areas (in the absence of interference or with uniform interference) complete area coverage requires the coverage range r_c of each transmitter to be equal to the largest of the distances from corners to centroid of the elementary triangle (see Fig. 8). Some coverage overlap is inevitable but for efficient coverage this should be minimized.

FIGURE 8

Examples of elementary lattice showing necessary overlaps to achieve complete coverage



a) Equilateral triangle



b) Non-equilateral triangle

Such minimum overlap results if the triangles are equilateral although the increase in overlap will be slight for small deviations from the equilateral condition. In this optimal condition, the parallelograms become rhombi, and the distance from each corner to the centroid of the triangle $= r/\sqrt{3}$. For this condition, the coverage area of each transmitter (*Sc*) is given by:

$$Sc = \pi\left(\frac{r}{\sqrt{3}}\right)^2 = \frac{\pi r^2}{3}$$

and the area of each parallelogram $S = \frac{\sqrt{3}\, r^2}{2}$.

The quotient *Sc*/*S* is known as the coverage factor (or alternatively *S*/*Sc* as the coverage efficiency). The highest value of *Sc*/*S* is that obtained with equilateral triangles and is equal to $2\pi/3\sqrt{3} = 1.21$. Despite giving a lower coverage efficiency, the use of a lattice with non-equilateral triangles may have advantages in some circumstances. This will be discussed when channel distribution is considered.

High co-channel protection ratios, of the order of 30-45 dB even for non-continuous interference, are required in television broadcasting. Consequently, co-channel coverage areas must not overlap but also be well separated. From the above explanations, it is clear that if the co-channel transmitters form an equilateral triangular lattice with distances, D, between neighbouring co-channel transmitters, the maximum coverage factor, c, will result:

$$c = 2\pi\, r_c^2 \Big/ \sqrt{3\, D^2}$$

Full area coverage will require the use of a sufficiently large number of channels, C. Identical co-channel triangular lattices for these C channels should then be superimposed in such a way that the resulting lattice is entirely geometrically regular again. The number of possible solutions to this problem is rather restricted.

All possible solutions can be found if the co-channel parallelogram (or rhombus) is subdivided by two sets of $C - 1$ equidistant lines, parallel to either pair of sides of the parallelogram. In Figs. 9a), and 10a), this is shown for an equilateral co-channel lattice and $C = 7$, or $C = 12$, respectively. Geometrical regularity of the resulting lattice of elementary triangles is obtained when each of the $C - 1$ parallels of one set contains just one transmitter. The $C - 1$ parallels of the other set contain also just one transmitter, if C is a prime number (e.g. 7). If C is the product of two or more primes, p_i, (e.g. $12 = 2 \times 2 \times 3$) there are also solutions whereas in the other set only parallels which are multiples of p_i (or of their products $\prod_{i=1}^{i<n} P_i$) carry p_i (or $\prod_{i=1}^{i<n} P_i$) transmitters (Figs. 10c) to 10e)). For $C = 7$, all possible solutions (except one which need not be considered as all transmitters would lie at one of the sides of the triangle) are shown in Figs. 9b) to 9f).

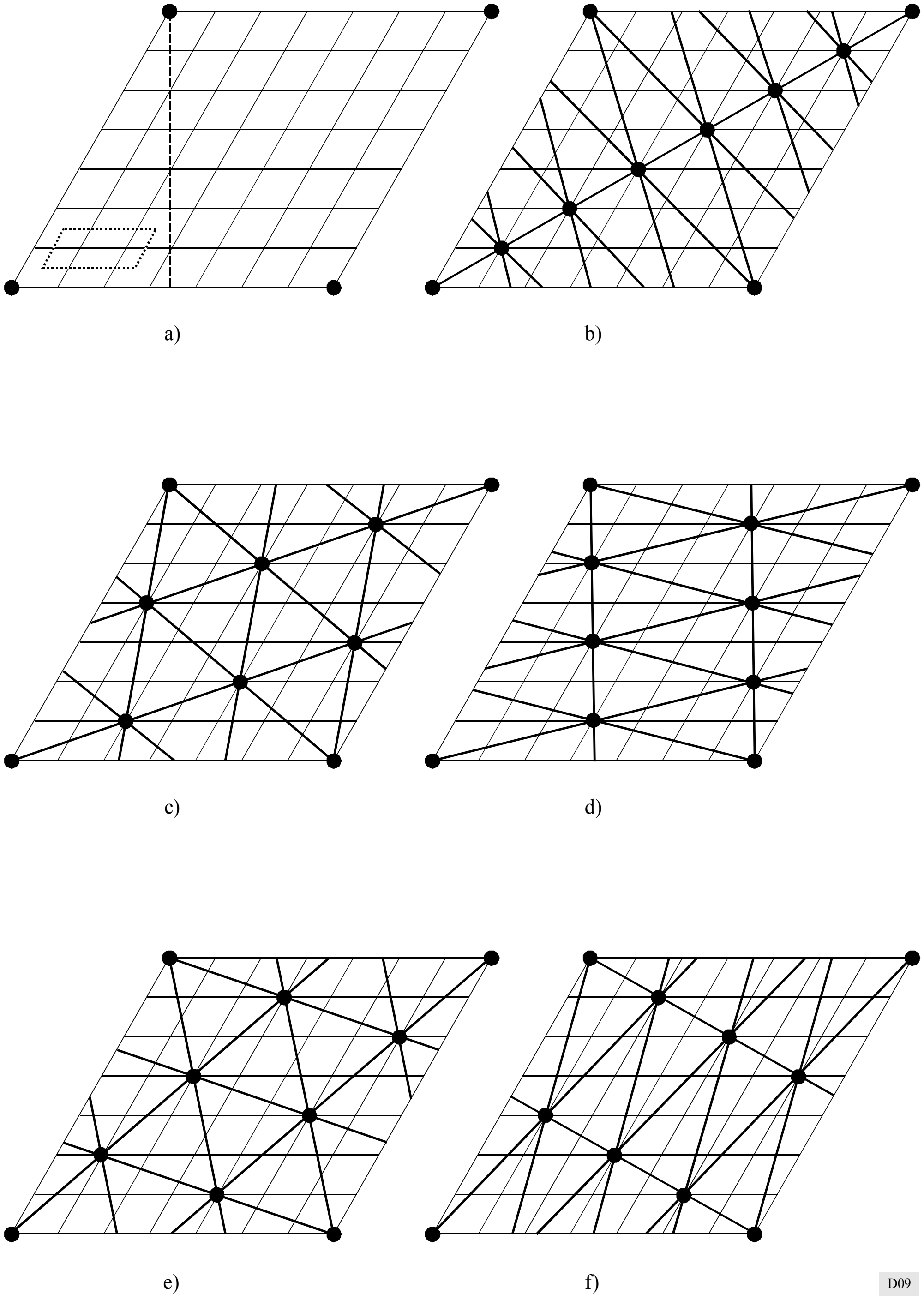
It is advantageous at this stage to introduce a system of non-rectangular coordinates (x, y) having its origin (0, 0) in the lower left-hand corner and the coordinates being directed towards the lower right-hand corner (x) or the upper left-hand corner (y), respectively. The subdividing parallels are at unity distance from one another.

In this system of coordinates, all the solutions of Figs. 9b) to 9f) have one transmitter at $y = 1$ but its position with respect to x varies between $x = 1$ and $x = 5$. The coordinates of all the other transmitters in each of the solutions are multiples of the respective first one, e.g. in Fig. 9b), the coordinates are (1, 1), (2, 2), (3, 3), (4, 4), (5, 5) and (6, 6). Coordinates exceeding C can be normalized by reducing the real multiple by C or by a multiple of C, as the original and the resulting values of the coordinate are congruent to each other modulo C.

It can be seen from Figs. 9b) to 9f) that some of the solutions are "symmetrical" ones (triangular symmetry) e.g. those of Figs. 9c) and 9e), or those of Figs. 9b), 9d) and 9f). This reduces the number of "genuine" solutions to two. Hence, it follows that, except for $C = 3$ with one genuine solution, all of them can be found if the coordinates of one of the transmitters are assumed to be $x \leq C/2$, and $y = 1$ (or *vice versa*), i.e. to the left of the dashed vertical lines in Figs. 9a) and 10a) and, more precisely, inside the parallelogram formed by dashed lines. Thus, in the example of Fig. 9 ($C = 7$) only the coordinates (1, 1) and (2, 1) need to be considered, whereas in the example of Fig. 10 ($C = 12$) only "genuine" solutions are presented.

FIGURE 9

Derivation of possible channel distribution for an equilateral co-channel lattice with $C = 7$



a)

b)

c)

d)

e)

f)

The solutions of Figs. 9 and 10 are derived from an equilateral co-channel triangular lattice. In such a lattice the square of the distance, d, between coordinates $(x1, y1)$ and $(x2, y2)$ with $(x2 - x1) = a$ and $(y2 - y1) = b$ is $d^2 = a^2 + ab + b^2$. In Figs. 9 and 10 the co-channel rhombus has a sidelength, D, which corresponds, in either case, to C units, and an area $S = \sqrt{3}\, D^2/2 = \sqrt{3}\, C^2/2$. If this area is subdivided into C congruent elementary parallelograms, each area will be $Sc = \sqrt{3}\, C/2$, and in the case where the elementary area is a rhombus, $Sc = \sqrt{3}\, d^2/2$, i.e. $d^2 = C$. Figures 9 and 10 show that the elementary triangles are, in general, not equilateral and have sidelengths d_1, d_2 and d_3. Only in exceptional cases (Figs. 9c) and 9e)) is the elementary triangle equilateral. Solutions where both the co-channel and the elementary triangles are equilateral exist only when C is a rhombic number, i.e. when there are two integers, a and b, which fulfil the equation $C = a^2 + ab + b^2$. This is a consequence of the fact that the coordinates of all transmitters can only be integers. Equality of the areas of equilateral and non-equilateral triangles exists if:

$$3\,d^4 = 4\,d_1^2\,d_2^2 - \left(d_1^2 + d_2^2 - d_3^2\right)^2$$

Example: in Fig. 10d) the sidelengths are:

$$d_1 = \sqrt{13}, \quad d_2 = 3, \quad d_3 = 4$$

hence:

$$3\,d^4 = 4 \times 13 \times 9 - (13 + 9 - 16)^2$$

or:

$$d^2 = \sqrt{(13 \times 12) - 12} = 12 = C$$

Values of rhombic numbers for $C < 80$, together with originating integers a and b are given in § 2.1 of the main text. This also lists some of the basic conclusions derivable from the above considerations of the present Annex.

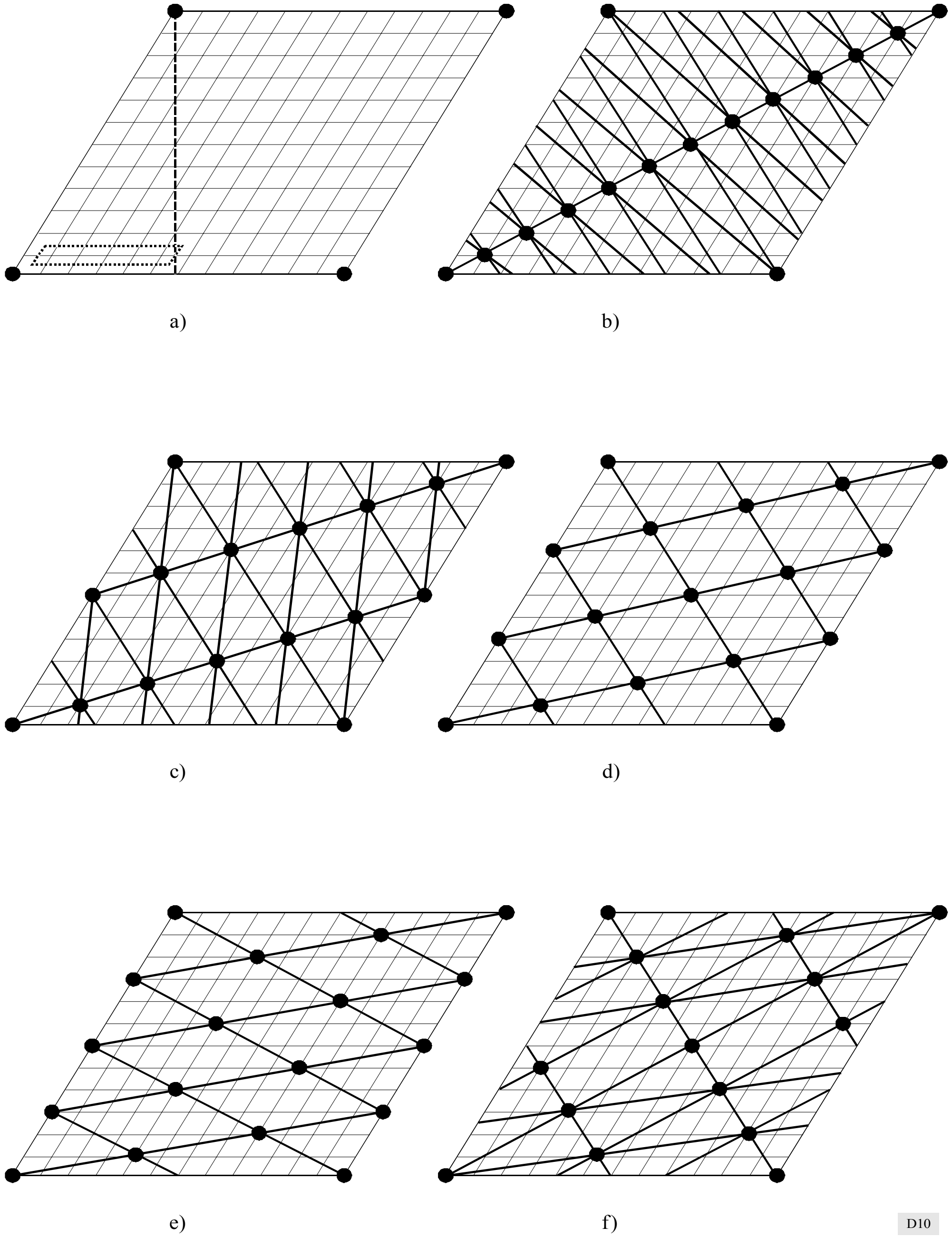
Some further conclusions are also possible:

- if transmitters situated at the corners of the co-channel rhombus suffer interference from other transmitters situated elsewhere on the area of that rhombus and using different channels, e.g. adjacent or image channels, then the distance of such transmitters from the corners should be maximized, i.e. they should be situated as closely as possible to the triangles centroid. Such interference will, nevertheless, lead to a reduction in coverage and, to compensate for this loss, an increase in the required number of channels will be necessary;

- the effect of interference depends mainly on the distance between the transmitters involved and the protection ratio required. Because of the smaller distance between the centroid and the corners of the co-channel triangles, it may happen that co-channel interference is no longer predominant. This does not apply to most television systems. For information, it may be noted that it applies particularly in the case of adjacent-channel interference at 100 kHz spacing in FM sound broadcasting. In such circumstances, equilateral elementary triangles may be preferable to equilateral co-channel triangles. However, regardless of what solution is chosen, the number of channels required for full area coverage will increase.

FIGURE 10

Derivation of possible channel distribution for an equilateral co-channel lattice with $C = 12$



3 Linear channel-distribution schemes

Having established the geometric nature of the lattice, it remains to find an arrangement for the C channels necessary for full coverage in such a way that interference is minimized. At this stage it seems appropriate to recall that every co-channel rhombus is part of an infinitely extended lattice consisting of C regularly superimposed co-channel lattices. Each result obtained by the lattice-planning method will therefore be characterized by a periodical repetition in all directions of the geometry and channel arrangement shown, by way of examples, on the area of a co-channel rhombus.

For the purpose of channel-arrangement considerations, it seems appropriate to use channel number 0 as a reference and to assign it in any one example to the corners of the co-channel rhombus. As a consequence, the numbers of the channels (1, 2, ... $C - 1$) in the arrangement will automatically be characteristic of the difference in channel numbers between the transmitter under study and those at the corners of the co-channel rhombus. However, when considering, as an example, adjacent-channel interference, it must be borne in mind that this type of interference does not only exist between channels 0 and 1, but also between channels 1 and 2, 2 and 3, etc. For reasons of simplicity and for reasons of the regularity of the resulting channel-distribution scheme, it seems appropriate to assign channel 1 to a transmitter at coordinate ($x1$, $y1$) which, according to earlier explanations, should be fairly close to the centroid, and channel 2 to the transmitter at coordinates ($2x1$, $2y1$), etc. This implies that channel numbers assigned to equidistant transmitters situated along a straight line will have the same difference. If this difference is greater than 1 channel, numbers greater than C may result which should be normalized by subtraction of C, or a multiple of C. The original and normalized channel numbers are, thus, congruent to each other modulo C. The resulting channel-distribution schemes are called linear distributions. Of course, other solutions exist, but non-linear distributions, although not necessarily useless, are less manageable, these are discussed briefly in § 5.

For the study of coverage efficiency, the consideration of linear channel-distribution schemes is advantageous since the interference situation in each of the C superimposed co-channel lattices is identical, except for some irregularities linked to the lower and upper of the C channels. This exception can, however, be disregarded if the C channels are assumed to form a cyclical system of channels where channels 0 and $C - 1$ are adjacent to each other. Such adjacency would, by the way, result if it were attempted to obtain coverage with n programmes by using a sequence of subsequent channels subdivided into n groups of C channels each. A cyclical system of channels is shown in Fig. 11.

As the interference situation in all C channels as well as for each transmitter in any one of the co-channel lattices is identical, the coverage areas of all transmitters are also identical, both in size and shape. Verification of the coverage obtained by all transmitters in the C channels does, therefore, not require more than the determination of the coverage area of one single transmitter.

Linear channel-distribution schemes also allow interference other than co-channel to be taken into account. For the television service, these include interference from the adjacent channels (± 1), from the image channel (+8 or ± 9 or +10) and from the local oscillator of a receiver tuned to channel ± 4 or –5. These channels should ideally be located in the vicinity of the centroid of one of the two triangles forming a co-channel rhombus. Their distance from the corners should, in principle, be larger if the protection ratio is greater. In linear channel-distribution schemes, for reasons of symmetry, channels with equal difference from that of the reference transmitter but of opposite sign are at symmetrical positions relative to these two centroids.

Remembering that channels z and $C - z$ are symmetrical to each other, there can obviously exist no more than $C/2$ different channel distributions, i.e. taking the example of Fig. 9b), only three; these are shown in Fig. 12 and indicated in the three columns. The two centroids are marked by the symbol G. The third solution would provide the largest distance from the corners to the adjacent-channels. In the example of Fig. 9c), the distance of each transmitter from the nearest corner is identical; hence, the possible three solutions are, in this case, equivalent, so that in reality there exists only one single "genuine" solution because of additional symmetry. This special condition occurs where C is a rhombic number and the lattice comprised of equilateral triangles.

FIGURE 11

Cyclical system of channel grouping (*n* = 2)

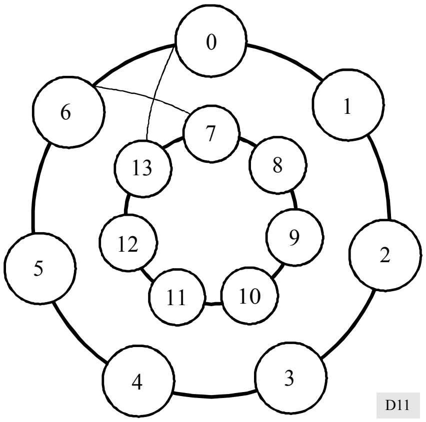
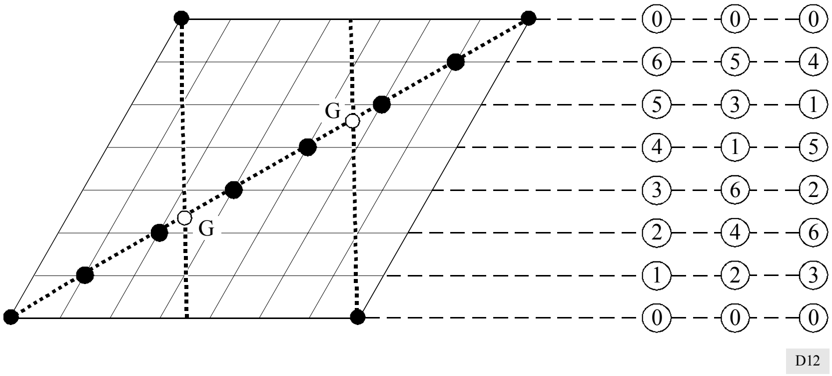


FIGURE 12

Examples for channel allocation in a regular equilateral lattice (*C* = 7)



The number of possible solutions increases, in principle, with the number of channels necessary for full coverage. However, the difference in channel numbers, Δ, between neighbouring transmitters and the numbers of channels available, *C*, should have no factor (other than 1) in common, since in such a case only channel numbers that are multiples of this common factor would be used, whereas the remaining channel numbers would be unused. It is obvious that in such circumstances no linear channel-distribution scheme could ever be obtained. Hence, the full number of *C*/2 solutions (the integral part of this fraction) will only exist if *C* is a prime number. If *C* is the product of two or more primes, the number of solutions is considerably lower. For $C = 12$, for example, only two solutions exist; they are shown in Fig. 13 for the geometry example of Fig. 10f). Once again the two centroids are marked by the letter G. Neither solution is entirely satisfactory when used with this geometry.

FIGURE 13

Examples for channel allocation in a regular equilateral lattice ($C = 12$)

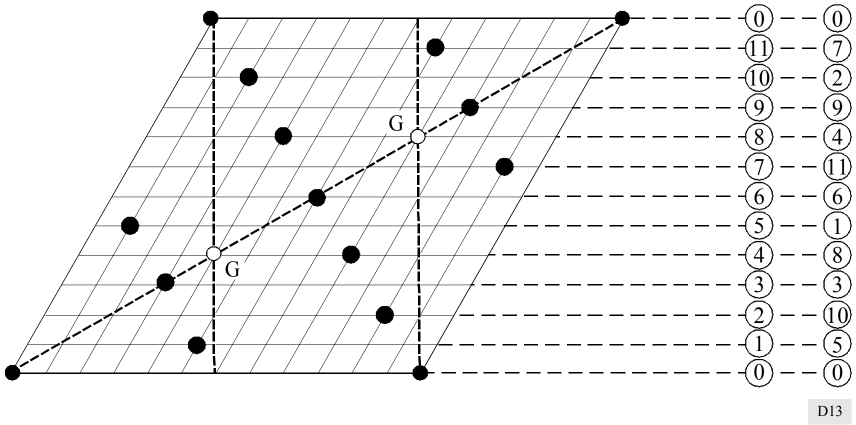


Figure 14 shows an example for $C = 19$, the elementary triangles of this solution are equilateral. The channel-distribution scheme selected is fairly appropriate for UHF television broadcasting systems G, I or L, as it takes the best possible account of interference with channel differences of 1, 9 and 18, assuming that the 61 channels comprising the full UHF band are subdivided to provide three programmes each with 19 frequencies. The distance of these channels from the corners are $\sqrt{3}$ times, 2 times and $\sqrt{3}$ times the sidelength of the elementary triangle, respectively. The position with a channel difference of 5 is fairly unsatisfactory, as it is immediately adjacent to that of the reference channel. It can easily be verified that, with this geometry, no solution can be found for which the channel differences of 1, 5, 9 and 18 are all equally good and satisfactory.

It can be concluded at this stage that the problem of achieving full area coverage can be solved, using the flow-chart of Fig. 15 by determining:

Step 1: The coverage factor, $c_{(1)}$, when only one channel is used and when, in the absence of noise, account is only taken of co-channel interference:

$$c_{(1)} = 2\pi \, r_{(1)}^2 \Big/ \sqrt{3} \, D^2$$

Step 2: The minimum number of channels, C_{min}, necessary to provide full coverage: $C_{min} \cong 1.2/c_{(1)}$.

Step 3: The most favourable geometry (equilateral or near-equilateral elementary triangles) for C_{min} or slightly larger values, if necessary or appropriate.

Step 4: The most appropriate channel-distribution scheme for the geometrical solution of Step 3.

Step 5: The coverage factor, c_1, obtainable with any of the C channels taking account of all types of interference:

$$c_1 = 2\pi \, r_1^2 \Big/ \sqrt{3} \, D^2$$

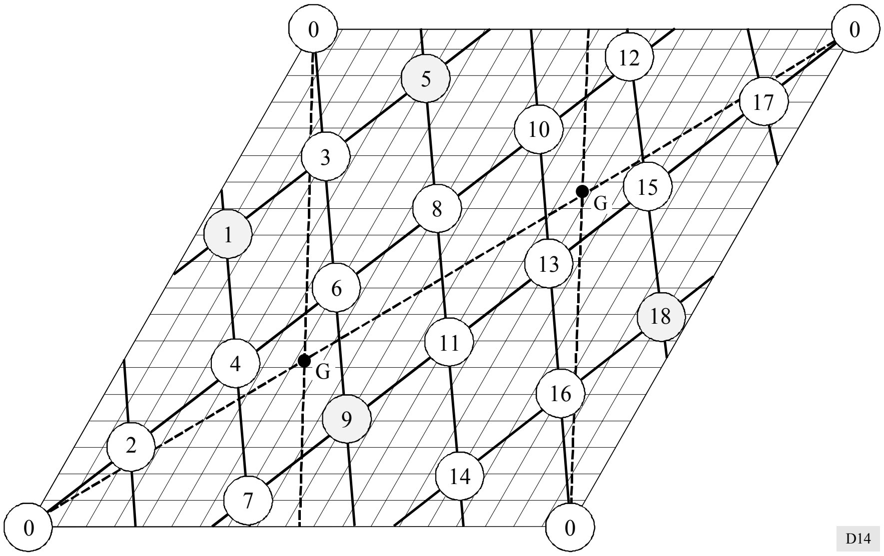
Step 6: The coverage factor, c, obtainable with all channels: $c = c_1 \, C$.

Step 7: The power level necessary to permit noise-free reception at a distance r_1 from the transmitter for about 90% of the locations:

- to obtain the optimum result, Steps 3 and 4 may require repetition in an iterative procedure;
- if the power level determined in Step 7 exceeds a reasonable or a predetermined value, either the co-channel distance, *D*, has to be reduced and the whole procedure to be repeated, or the number of channels, *C*, has to be increased;
- if in Step 6 the resulting coverage factor, *c*, is not equal to (for equilateral elementary triangles), or sufficiently greater than (for non-equilateral elementary triangles), 1.2, the whole procedure has to be repeated starting either with Step 3 or, if necessary, from the beginning, however with an increased value of *C*. An affine transformation may be of help, if interference from other channels exceeds, or is comparable to, co-channel interference.

FIGURE 14

Example of 19-channel lattice – Appropriate for UHF television in the case of three programmes to the provided in separate sub-bands



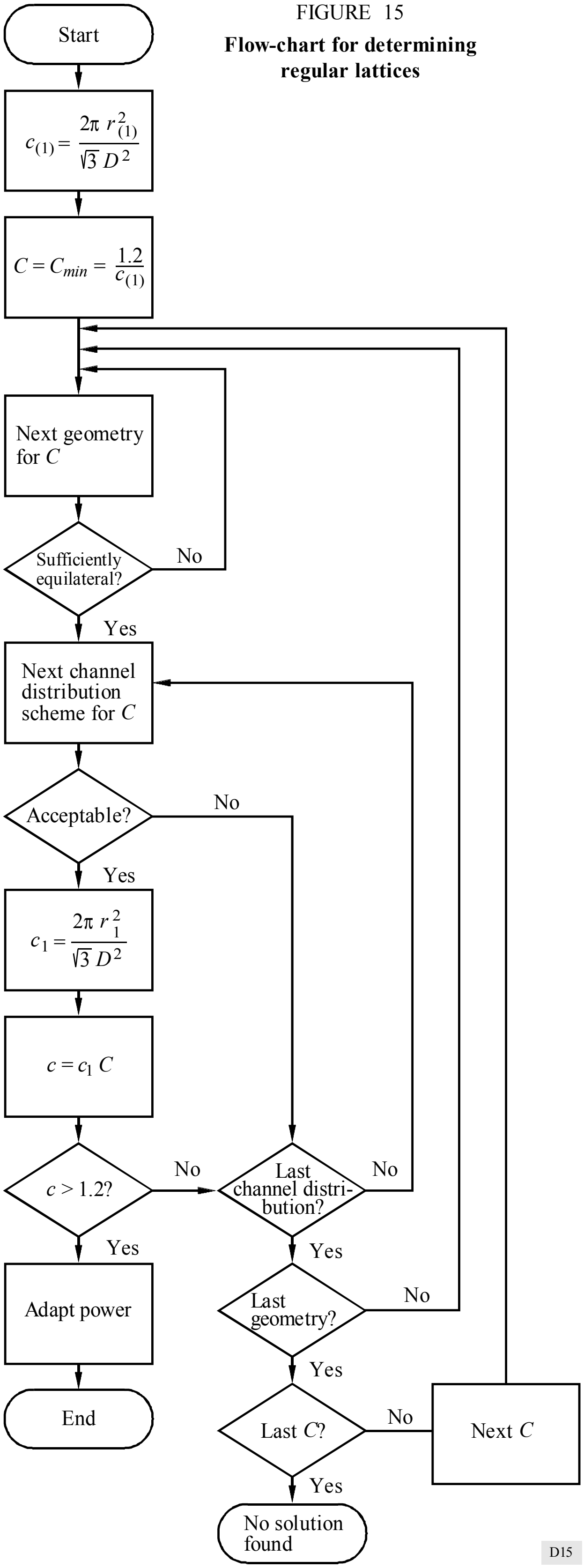
4 Multiple coverage and channel grouping

Having solved the optimization problem of obtaining full area coverage with a minimum number of channels, it is fairly easy to solve the problem of providing full area coverage with more than one programme. It is obvious that the number of channels, *C*, necessary for coverage with *P* programmes is $C_P = CP$. This may be achieved either:

- by extending the cyclical system of *C* channels to comprise *P* cycles of *C* channels each; in Fig. 11 this solution is shown for $C = 7$ and $P = 2$. This solution takes advantage of the fact that in a cyclical system channels $C - 1$ and *C* are already adjacent to each other. Hence, in principle, no further interference will need to be considered with the only exception of those types of interference which were not previously involved because of the small number of channels used. For example, in Fig. 12, as only 7 channels are used, no image-channel interference can arise from channel +9. This will change when multiple coverage with 7 channels per programme is envisaged since channel 2 in the second network is 9 channels above channel 0 in the first network, etc.;
- by treating the entirety of C_P channels as a whole, i.e. a single lattice of C_P channels.

FIGURE 15

Flow-chart for determining regular lattices



The first method ensures identical coverages with *P* programmes, apart from specific exceptions such as smaller adjacent-channel interference levels on the highest and lowest channels. It provides equal channel spacings of transmissions at each site, which can be considered to have both advantages and disadvantages. The second method is more flexible since the number of lattice solutions increases with total number of channels. It involves grouping together *P* lattice assignments at each single site. These should be selected from points in close proximity to each other. If more than two channels are grouped at a single site and the channels are obtained from a straight line through the lattice, they will, as with the first method, have equal spacings.

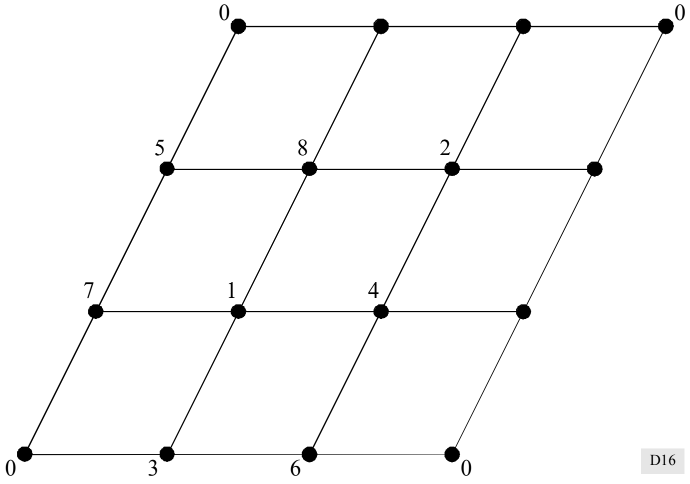
The grouping implied in the second method involves a certain amount of distortion of the basic lattice. This need not be detrimental but it is obvious that it is the elementary triangles resulting from the grouping rather than those of the original basic lattice which should be near-equilateral. For this reason basic solutions with elementary triangles which are far from equilateral may be of interest.

5 Non-linear distributions

It was stated earlier that non-linear channel distributions may also provide valid solutions, but are generally less manageable. Figure 16 shows such a non-linear distribution based on a 9-channel lattice by way of example. This has the feature of providing a lattice with co-channel and elementary triangles that are both equilateral even though 9 is not a rhombic number. It may be seen that this distribution does not have the property of equal steps in channel numbers in any one direction through the lattice. Because of this, interference levels will not necessarily be the same at all transmitter locations.

FIGURE 16

Example of non-linear network for 9 channels



ANNEX 2

Frequency planning constraints
(625-line systems)

1 Introduction

In order to ensure effective planning of terrestrial television broadcasting services in the frequency ranges 47-68 MHz (Band I), 174-230 MHz (Band III) and 470-960 MHz (Bands IV and V), it may be necessary to take into account certain constraints on the use of frequencies in order to avoid interference to other TV broadcast transmissions and to ensure compatibility with other broadcasting services, e.g. with the sound broadcasting service in the frequency range 87.5-108 MHz.

This Annex identifies the constraints that may result from the technical limitations of receiver design and also from the transmission of several TV and VHF/FM sound broadcast programmes from the same site or from non co-sited transmissions with overlapping service areas. Co-channel, adjacent-channel and image-channel transmissions are dealt with in Recommendation ITU-R BT.655.

Interfering signals can be maintained at acceptable levels by ensuring sufficient geographical separation between the transmitting stations involved, but the limited part of the spectrum allocated to television broadcasting services requires economy in frequency usage and demands the re-use of channels at distances as short as possible.

No account is taken of interference resulting from radiation of harmonics and intermodulation products at transmitter sites, on the assumption that the broadcasting authority can take the necessary precautions to reduce such spurious radiation to acceptable levels.

2 Constraints introduced by television broadcast receivers

2.1 Television receiver local-oscillator radiation

Because of the possibility of interference being caused by the use of superheterodyne receivers, the use of certain channels is precluded. Except for system L and some system K1 receivers, local oscillators operate at frequencies between 38.0 and 40.2 MHz above the vision carrier of the wanted signal. Hence, if the channel separation is 7 or 8 MHz and channel n is used by one service, the choice of channel $n + 4$ or $n + 5$ for a neighbouring service depending on the system used (see Table 1) would result in interference being caused from local oscillators in receivers which are tuned to channel n. For system L and some system K1 receivers, the local oscillator operates at a frequency 32.7 MHz below the vision carrier of the wanted signal and the affected channel in this case is $n – 4$.

The above information is derived from Report ITU-R BT.625.

Additionally, with such a difference in channel numbers, interference caused by an intermediate frequency beat may occur. In practice, these problems are gradually decreasing with improved receiver technology.

Radiation from television receivers in the range 47-68 MHz may affect VHF/FM reception. This may occur when the television local-oscillator frequency lies near the carrier frequency of a VHF/FM transmission.

2.2 Image channel

Image-channel interference occurs when transmissions are separated by about twice the intermediate frequency. The image channel affecting receivers tuned to channel n would be $n + 9$, except for systems B ($n + 10$), for systems D and K ($n + 8$ and $n + 9$), system K1 ($n + 9$ and $n + 10$) and system L ($n - 9$).

Although the improved image-channel rejection characteristics of modern receivers minimize the problem, rejection is not complete and the situation should be avoided in preparing a frequency plan. Image-channel interference is not a problem within Bands I and III.

2.3 Harmonics from VHF/FM receiver local-oscillators

Second or third harmonics of VHF/FM receiver local-oscillators, depending on whether the local-oscillator frequency is high or low respectively, may fall within Band III. It would therefore be preferable to choose the VHF/FM transmission frequencies and the television channels in such a way that this condition does not occur; however, this can not be generally taken into account when preparing frequency plans.

2.4 Harmonics and intermodulation products generated under overload conditions in receivers

High input levels of VHF/FM and/or television signals can lead to non-linearities in the input stage of receivers, giving rise to the generation of harmonics and intermodulation products. A general consideration of such interference mechanisms when elaborating a frequency plan is not possible. Problems should be solved on an individual basis, e.g. notch filters and attenuators might be used in the receiving installation.

3 Transmitting antenna system limitations

In many instances, co-sited television transmissions may utilize a common antenna system. The minimum possible frequency separation is determined by the practical design limitations of combining units.

For planning purposes, the minimum frequency spacing should in general be not less than 2 channels in Bands I and III and 3 in Bands IV and V. Although it is also technically feasible to design combining units to operate at spacings down to 2 channels in Bands IV and V, these may become more expensive, particularly for high power transmitters.

It is theoretically possible to assign adjacent-channels to co-sited transmitters provided that two emissions are orthogonally polarized and with similar ERP. However, there are likely to be significant engineering problems at the transmitter site. In addition, severe problems are to be expected at receiving installations which will have to use separate antenna systems to receive the two signals.

4 Conclusions for television planning procedures

Table 1 indicates, for the various television systems, the differences in channel numbers which should be avoided for co-sited transmitters, because of radiation from local oscillators or image-channel interference. For non co-sited transmitters with overlapping coverage areas, the problems are considered to be less severe. It would be prudent, however, to avoid those channel relationships in initial planning.

TABLE 1

System	Difference in channel numbers	
	Local-oscillator radiation	Image-channel interference
Bands I and III		
B, I, K1	5	–
D, L, K1(1)	4	–
Bands IV and V		
B	5	10
D, K	4	8, 9
G, H, I	5	9
K1	5	9, 10
L, K1(1)	4	9

(1) If the same local oscillator frequency as system L is used.

It should be noted that these constraints refer to uniform channel spacing for the whole planning area. In the case of transmitters using different systems and/or different channel spacings, with overlapping coverage areas, a detailed case-by-case investigation is necessary.