# TWENTY-ONE YEARS OF TE

## (PART 2)

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## Theories of tep

### Transequatorial scatter

Before the IGY the abnormal 28, 50 and 56MHz propagation which had been observed by amateurs to take place across the equator was termed "transequatorial scatter propagation". Since forward and backscatter were frequently in evidence, the tropical ionosphere at night was thought of as a turbulent zone rather like the auroral zones. With the discovery that not only weak and fluttery, but also abnormally strong signals sometimes appeared in the early morning, and from midday and persisting late into the night on frequencies as high as 90MHz, the term "scatter" became clearly inappropriate and it was dropped from the amateur terminology.

With the advent of 144MHz QSOs across the equator, the scatter mode has been revived, notably in articles by W1JR [7] and DJ3KR [8], and the presence of abnormally strong signals either ignored or dismissed as an entirely different mode of propagation.

Reflection from a single scattering zone even 1,000km high could not account for propagation between Athens and Pretoria, or between South-West Africa and northern Italy, and would require very low angles of radiation between Salisbury, Cyprus and Athens (which is clearly not the case). Evidence of sufficiently dense ionizations to reflect, rather than just scatter from irregularities, at 144 and 432MHz at any altitude over the magnetic equator, is lacking. Further, if either a single or multiple scattering were the supporting mode, then the power required would increase rapidly with frequency, as it does with meteor scatter signals, and this was comprehensively proved not to be the case when communication between Salisbury and Athens took place using a mere 40W and the tiny antenna shown in the photograph in Part 1.

### The billiard ball mode

Observations from a ground backscatter sounder operated from the Virgin Islands in 1956 were noted by Professor O. G. Villard Jnr, W6QYT. These led him to propose a mode of propagation whereby successive reflections could take place from the F2 layer without intermediate ground reflections, as a result of tilts in the height of the F2 layer caused by the post-sunset rise in the ionosphere over the magnetic equator [9].

The ray geometry so proposed represented a considerable advance over the earlier scattering theory and could be used to explain most of the phenomena being observed and the geographical distribution of the te zones. If an optimum tilt could be found in the layers on either side of the magnetic equator, then the angle of incidence was much lower than with normal nF2 reflections and the frequencies propagated would be higher. However, there were obvious snags with the theory; as any billiard player will point out, the angles are very critical. Villard claimed to have found the requisite tilts to exist in small appropriate areas of the ionosphere around 1700 local time. There is most certainly a rise in the tropical F-region after sunset, and a maximum is reached about 2000 local time, after which the F-region over the magnetic equator descends. Height variations sufficient to give the minimum required 13° tilts for propagation between Salisbury and Cyprus are indeed difficult to find, and the chances of their persisting from early evening through to the early hours of the morning are quite negligible.

However, a variation suggested by ZE2JV in 1960, namely that the ionization gradient rather than the variation in virtual height of the F2 layer provided the necessary tilts, may be combined with Villard's theory to provide a plausible concept to explain the strong signals received by F-type te.

### The exospheric mode

As a result of backscatter soundings southward from Japan, Professor T. Obayashi proposed in 1959 that, as 28MHz transmissions would penetrate the ionosphere, tep could take place in a similar manner to vlf whistlers, along field-aligned ionizations in the exosphere (now termed the magnetosphere) [10]. The suggestion was taken seriously at the time and it focussed attention on the work being done by the authors of this article. According to this theory, te signals should come down at the geomagnetically conjugate point, and there is indeed a tendency for them to do so. However, due to the magnetic anomaly, Cyprus and Salisbury are certainly not geomagnetically conjugate. Further, assuming a perfect dipole magnetic field for the earth, the authors calculated that the return trip by the exospheric mode should take about 58ms. They thereupon set up their first time-delay experiment, but the results listed in Table 1 in Part 1 discredited the suggestion.

However, Obayashi's suggestion cannot simply be discounted. He was evidently aware of the relatively high angles at which te takes place (as against the very low angles required by Villard's suggestion). Field-aligned ionizations are really present, and the only error is that the alignment and the ducting of signals takes place within the ionosphere, rather than through the magnetosphere. The discovery of 144MHz propagation caused the authors to look at Obayashi's theory again, and once again prompted interest in time delays. They were reminded that tep does show an extra time delay, which undoubtedly leads to errors with backscatter sounders, and the only explanation they can offer for this extra delay is ducting along field-aligned ionizations, as suggested by Obayashi.

## Towards a better understanding of tep

### Large scale events in the ionosphere

The ionosphere is directly influenced by solar radiation, and it might be expected that the density of ionization should show a maximum over the equator at the equinoxes. In practice, as far as the tropical ionosphere is concerned, there is very considerable modification. At the equinoxes there is not one maximum but two. These maxima begin to form in the morning, and a pronounced "bite-out" between them becomes well-established by noon and lasts until after midnight [6]. Further, this system is centred not over the true equator but over the line of zero magnetic dip, or magnetic equator.

The system does not, as might be expected, move north and south with the seasons, but with the migration of the vertical sun in summer and winter the system becomes unbalanced, with considerable differences in the electron densities in the high density areas which form in the regions approximately 10°–15° from the magnetic equator. At the equinoxes electron densities in these zones are comparatively very high, and critical frequencies at vertical incidence (foF2) of up to 20MHz and more were recorded in South America during the IGY.

The influence of the earth's magnetic field is marked. Not only is the anomaly symmetrical about the magnetic equator, but the ionosphere is upset by magnetic storms and influenced by changes in the magnetic field. Results from satellites have revealed the surprising information that the earth's field in space is not the neat dipole field it was presumed to be but is compressed against the earth on the sunny side by the solar wind and is extended far into space on the side away from the sun. The earth and its ionosphere rotating within this field thus encounter a rapid change shortly after sunset. The resultant dynamo action sets up strong electric fields, the lower levels of the ionosphere are sucked up, and the upper levels bulge outwards and reach a maximum about two hours after sunset. The plasma then shatters, the turbulent regions subside and the irregularities so formed align themselves with the earth's magnetic field. Meanwhile at lower levels the absence of a coherent bottom in the E-region prevents the shorting out of electric charges and hence inhibits recombinations so that ionizations persist until very late at night.

**Smaller-scale events and the propagation of vhf/uhf signals**

The size of the irregularities may vary considerably and kilometre and metre sized irregularities may co-exist; they are mobile and drift about in clouds which may be kilometres in length and only a few metres in width. In addition they are responsible for the scintillation of radio stars, and have been found to produce rapid fading on frequencies as high as 2,000MHz of signals coming through the ionosphere from stationary satellites. As well as the irregularities, plasma bubbles are known to rise through the turbulent regions of the ionosphere, and these have been shown to cut off signals from exploratory rockets as they pass through the plasma.

Except in years of exceedingly high solar activity (such as experienced during the IGY when signals in the lower vhf range could be propagated like hf signals by multi-hop F-layer reflections) vhf and uhf must be considered as frequencies which will penetrate the ionosphere. Reflections in the normal way cannot be considered, but bending or refraction may take place where steep horizontal ionization gradients are encountered and ducting is also possible.

Such horizontal gradients are known to exist on either side of the magnetic equator on the verges of the high-density zones, so that at vhf these zones may function more like lenses than mirrors. Thus a wave entering a high-density zone where there is no gradient and leaving where the gradient is steep will be bent and, when the bending is sufficient, the wave will be propagated across the magnetic equator to meet a similar lens on the other side where, if the electron density is sufficiently high, it will be refracted back to earth.

When the "lenses" are clear, like polished glass, very strong signals and a degree of focussing can be expected. One can also expect to find a clearly marked muf and, within the vhf range, a hierarchy of signals whereby the lower frequencies appear sooner and disappear later than the higher frequencies. This is exactly what the authors found in the ZE2TEP experiment [2] and the system, which is illustrated in Fig 12, is probably responsible for most of the signals which they label "F-type te", and is capable of propagating signals up to 90MHz under the most favourable conditions.

Spread-F phenomena have a particular relevance to tep. Like many other ionospheric phenomena, the appearance of spread-F varies considerably with the seasons and the sunspot cycle, and the distance away from the magnetic equator affected by it also varies sporadically. With its appearance, the underside of the F-region undergoes a change, as it were, from clear glass to frosted glass. Its name is derived from its effect upon vertical incidence ionosphere sounders upon which all evidence of a sharp critical frequency disappears. Just as light is scattered from frosted glass, so vhf signals penetrating the ionosphere tend to be scattered so that, instead of strong signals, weak signals emerge at the far end of the te circuit and forward and backscattering become prevalent.

About two hours after sunset the rise and break-up of the F-regions of the tropical inonosphere result in stratification of the high density areas along the lines of the earth's magnetic field. These ducts are of gentle curvature and tend to propagate signals, and if the signals are well above the cut-off frequency the ducts so formed will be insensitive to frequency. Thus the clearly-defined muf and hierarchy of signals which characterize "F-type te" disappear, and give way to the type of propagation the authors call "pure te".

The roughened undersurface of the F-region is thought to play a dual role. It seems to play the part of a receiving and retransmitting area, so that, if energized, it retransmits the signal into the field-aligned ducts and, on receiving a signal from the ducts, seems to spread it in all directions. At times, as evidenced by the beam rotation tests, the signal appears to come from the whole of the visible sky, as if it were all illuminated by the signal. Where the spread-F is patchy, off-line transmission would seem to be probable, and it is thought that very strong signals that sometimes appear late at night may result from the absence of spread-F.

Apart from this specular action, the "frosted glass" effect is frequency sensitive and higher frequencies show a greater penetration. Hence it is a common occurrence for F-type te signals on 50MHz to fade out or to become very weak from about 1930 to 2030 local time, during which time 144MHz and higher frequencies are often propagated, and for the 50MHz signals to reappear later as "pure te".

Whether or not te signals continue to thread their way through the field-aligned ionization as they pass between the

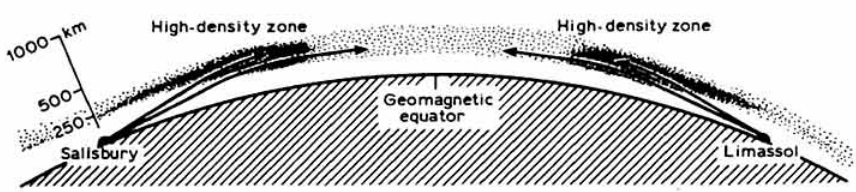


**Fig 12. Propagation via the high density zones 10°–15° from the magnetic equator (F-type te)**

high-density zones is again a matter for conjecture. It is evident, as illustrated in Fig 13, that the high density zones, while providing sufficient bending for the reception of satellites below the radio horizon, would not by themselves provide quite enough for the ray to encounter the opposite high-density zone. The extra bending is not great and DJ3KR [8] proposed a "bubble" to account for it. If this were the case the authors theory would approach very closely to his, since DJ3KR accounts for the geographical spread of tep by additional bending in the ionosphere and their difference would be merely one of emphasis.

However, the case for ducting is a very strong one. Over the geomagnetic equator the lines of force (along which the ionizations stratify) are parallel to the surface of the earth, and a system is required which (a) propagates signals over a wide frequency spectrum (28–432MHz), and (b) provides an extra but equal time delay (within the acuracy of the measurements) over the whole of this spectrum. It is doubtful if DJ3KR's bubble could satisfy either of these criteria, and a simple scattering model would suffer from the same defects. Nevertheless a plain ducting model would involve exospheric propagation on Obayashi's model [10], even allowing for the greater height of the F-region over the magnetic equator during the evening hours, and considerable modification is necessary.

First, the geomagnetic co-ordinates of the sending and receiving stations are relatively unimportant. Instead one must consider the magnetic lines of force operative in the area of the ionosphere illuminated by the signal. This may be 1,500–2,000km nearer the magnetic equator than the stations operating the circuit.

Second, the specular or "frosted glass" effect of spread-F enables the signal to be transmitted into ducts running more nearly parallel to the earth's surface than would otherwise be possible.

Finally, the whole area of the tropical regions of the ionosphere at night is turbulent, and the irregularities, although field-aligned, are mobile. What is a good duct one moment may disappear the next, so that a signal may switch its course very rapidly, an effect which may account for the on-off switching of the fading pattern and the frequency spreading, as well as allowing some of the signal to remain in ducts staying within the ionosphere instead of escaping into space.

The complicated flutter fading pattern of te signals may not be due solely to spread-F, although this undoubtedly does impart such characteristics to hf signals reflected from affected areas and to vhf/uhf signals propagated through them. A combination of spread-F and duct-switching must allow for a multiplicity of propagation paths varying in length (and time delay) by several wavelengths. With the complication of all these effects it is perhaps surprising that signals are even as coherent as they are and that signals are detectable at the power levels available to amateurs (which one hesitates to express as erp since antenna gain is seldom realized over te circuits).

## The future programme

Much remains to be done. Ed Tilton, W1HDQ, who over the years gave the authors much help and encouragement, wrote an article in *QST* April 1963 entitled "TE propagation—vhf discovery extraordinary" in which he paid tribute to te as a totally amateur discovery. It has continued that way. For many practical reasons much of the academic effort has concentrated on backscatter sounders, spread-F phenomena and topside ionosphere sounding from satellites. The difficulties of mounting long-range experiments over a considerable period of time on a professional basis are evident, but this is exactly what the amateur can do, with no extra cost except the expenditure of his time, which he willingly gives, and the use of his equipment, supplemented by loans from universities and professional sources when required.

The more immediate tasks which amateurs can undertake to further the knowledge of tep are as follows.

**1.** A full exploration of the possibilities of longer-range te, particularly at 144 and 432MHz.

**2.** Confirming or disproving the impression that stations must be equidistant and at right angles to the magnetic equator in order for tep to work.

**3.** A determination of whether tep will work at even higher frequencies. (Is it more ridiculous to try 1,296MHz than it seemed it would be to try 432MHz only a few years ago?)

**4.** The development of much more precise time-delay measurements than were possible some 20 years ago. These delays need to be measured with accuracies of the order of 0·5ms (ie ±150km or better) before what the authors have intimated in this paper as their impressions can be asserted with authority, namely that there is no significant difference in delay times from 28 to 432MHz.

**5.** The investigation on a systematic basis of the problem of angles of arrival. This task is of particular importance at locations further removed from the magnetic equator than Salisbury, Limassol and Athens. Such knowledge will not only confirm or refute the theory advanced but will also pave the way for amateurs to achieve the ultimate limits of the possibilities of long-distance tep.


## Acknowledgements

This report and the suggestions made to explain te phenomena are based on the combined efforts and willing co-operation of many amateur operators and experimenters over a long period of time, together with a study of the increasing volume of academic and technical literature dealing with the tropical ionosphere. It is not possible to mention all by name, but special mention must be made of Dr Fred Anderson, ZS6PW, for his technical advice and assistance in the timing experiments, and Professor Martin Harrison, G3USF, who undertook a search and supplied the authors with much of the literature.


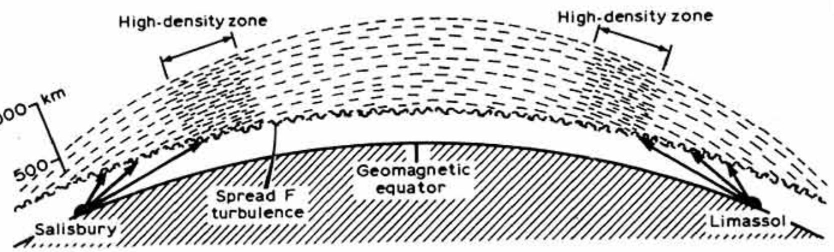


**Fig 13. Night-time development of spread-F and field aligned irregularities in the tropical ionosphere (pure te)**

The authors are also indebted to professional and university departments for their advice and assistance, and especially to the universities of Rhodesia and Athens, the BBC rebroadcasting station in Cyprus, the South African CSIR, and the Rhodesia Electricity Supply Commission.

## References


[1] "The transequatorial propagation of vhf signals", R. G. Cracknell, *QST* December 1959, pp11-17.

[2] "Results of tep 32-87MHz project" (1961-1962). HRB-Singer, Inc. State College, Pa.

[3] 'Transequatorial radio propagation during the years of the quiet sun", R. G. Cracknell and R. A. Whiting *RSGB Bulletin* June 1965, pp 367-70.

[4] Letter in *Dubus* No 4, 1978, from E. Mueller, YV5ZZ.

[5] "Transequatorial propagation of very high frequency radio signals", R. G. Cracknell, Proceedings, 1st Federal Science Congress, Salisbury, May 1960.

[6] "Special problems of hf radiocommunications associated with the equatorial ionosphere". *CCIR Report* No343-2, 1974.

[7] "A newly-discovered mode of vhf propagation", J. H. Reisert, W1JR, and G. Pfeffer, *QST* October 1978, pp 11-14.

[8] "Transequatorial dx contacts on 144MHz", J. Röttger, DJ3KR, *Radio Communication* December 1978, 1028-9.

[9] "Studies of transequatorial propagation by the scatter sounder method", O. G. Villard, S. Stein and K. C. Yeh, *Journal of geophysical research,* 62 1957, p399.

[10] "A possibility of long-distance hf propagation along the exospheric field aligned ionizations", T. Obayashi, *Journal of the Radio Research Labs,* **6**, 1959, p603. □


# Universal joint to prevent feeder breakages


by B. CASTLE, G4DYF*


ANYONE who has used white plastic 300Ω twin feeder out-of-doors will know how quickly it deteriorates; most troublesome of all is the tendency of the wire to break within the insulation at any point where it flexes in the wind. After several attempts to overcome the problem, the author developed the simple device described below which appears to overcome this fault liability. The device would be equally useful with the better-quality black plastic twin feeder which resists the effects of sunlight. If suitably modified to provide a suitable make-off, it could be used with coaxial feeders.

## The cause of breakages

When 300Ω twin feeder is hung from the centre point of antennas such as the G5RV, the Windom or folded dipoles, it is terminated at the top end on a T-shaped centre insulator and at the bottom end on the ground, a building, or on a vertical pole intended to remove some of the weight from the antenna.

When the wind blows, the feeder flaps about wildly, and if this movement is unrestrained the feeder will hinge at the lower fixed point. At the top end the flexure of the feeder is so slight, because the T-piece is free to twist axially from side to side with the antenna, that, in the author's experience, it does not lead to breakage of the conductors.

## The ideal device

The ideal device for damping the movement would have gradually increasing stiffness from the tip to the base, would be easy to fasten to the feeder or would enclose it, and would have negligible effect on the impedance of the feeder by its proximity. This last condition rules out metal or materials which

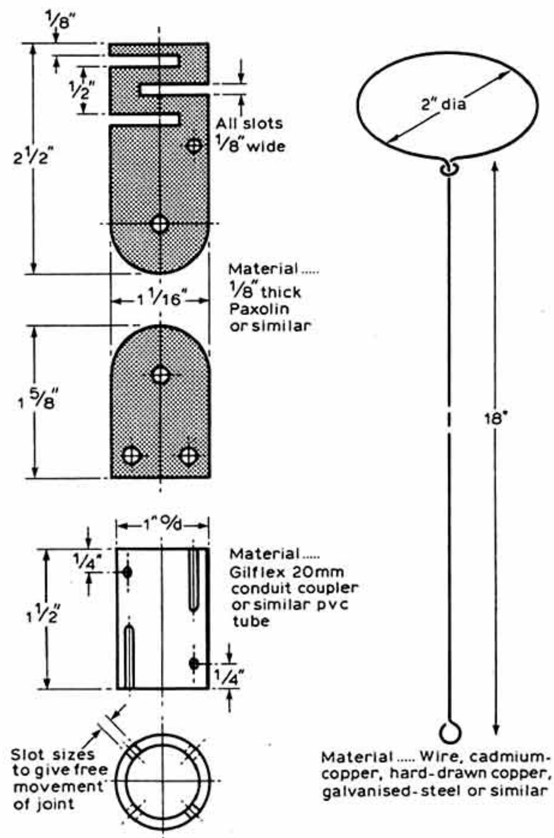


**Fig 1. Details of the joint components**


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The joint in use at the author's QTH

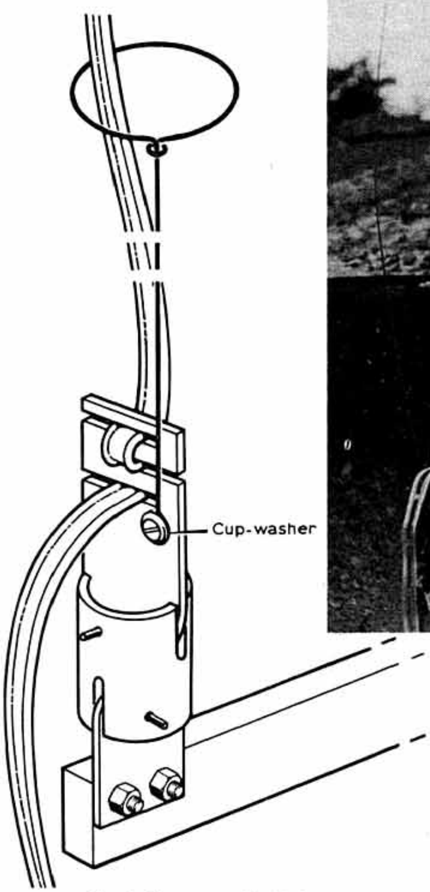


Fig 2. The assembled joint

conduct by virtue of absorbed moisture. A spiral plastic spring of graded stiffness through which the feeder passed would perhaps be ideal, but a source of such a spring has not been found; it would need to have negligible restraining influence at its top end.

## A practical device

The device which has been in use at the author's station for about two years is a simple universal joint with a springy wire extension, and this has prevented further breakages. The joint is made from a plastic conduit coupler of 1in outside diameter (Gilflex coupler for 20mm conduit) and two pieces of 0·125in thick Paxolin, plus a piece of stiff cadmium copper wire. Galvanized wire would no doubt serve equally well. Cutting details are given in Fig 1, and the assembled joint is shown in Fig 2.

The prototype was assembled using steel roll pins which were a tight fit in the holes drilled through the plastic tube; screws and nuts, plus lock-nuts should be just as satisfactory. The slots in the tube section must give sufficient clearance so that the Paxolin end pieces are free to swivel. The slots were made with a fine hacksaw and file.

The wire loop through which the feeder passes plays a vital part in the action, and without it the device would be completely ineffective in preventing fracture of the conductors. The wire acts as a lever to convey the movements of the feeder to the top part of the joint; without it, flexure at the make-off point would still occur because friction and inertia would not permit the joint freely to follow the feeder movements. There is some flexing of the feeder where it passes through the wire loop, but this is minimal and is spread over an appreciable length of the wire. The zig-zag fastening of the feeder to joint permits easy removal or adjustment.

Incidentally, it may be noticed that the feeder sags more at one time of day than at another. This appears to be caused by a change in the moisture content of rope halyards; even nylon ones are subject to this. A fraction of an inch change in the length of a tightly stretched halyard will cause perhaps an 8in change in the height of the feed point above the ground. □

# The gain of the quad

*(Continued from page 784)*

Hardly surprisingly it was found that the gain increases when the elements are vertically extended, since the distance between the points for maximum current then reaches its maximum. On the other hand it came as a surprise that the gain of the normal quadratical element is only 0·98dB over a $\lambda/2$ dipole. Since the distance between the two points of current maximum does not increase when the antenna length increases, this means that a long quad antenna can be regarded as two Yagis much too closely spaced where the gain difference of 0·98dB continuously reduces. The gain difference between a quad and a Yagi of equal length could therefore be expected not to exceed 1dB throughout.

When comparing the different forms between themselves it was noted that the elliptical form is somewhat better than the rectangular, which in turn is better than the rhombical. It must be remembered, however, that this is mainly a reflection of the distance between the feedpoint and its diametrically opposite point, and also to some extent of the inclination of the element part.

If more gain is wanted it is thus recommended that the elements be extended vertically, but it must be remembered that the more gain one tries to press out of an antenna of given size, the more the impedance and the bandwidth will decrease. The antenna will become more and more critical and the risk of failure will increase.

## Conclusions

The difference in gain between a quad with quadratical elements and a Yagi of equal length with an equal number of elements is approximately 1dB for short antennas. For long antennas the difference can be expected to be smaller.

The gain can be increased at the expense of bandwidth, impedance and, to some extent, efficiency (gain will be lower than directivity) by extending the elements vertically. □