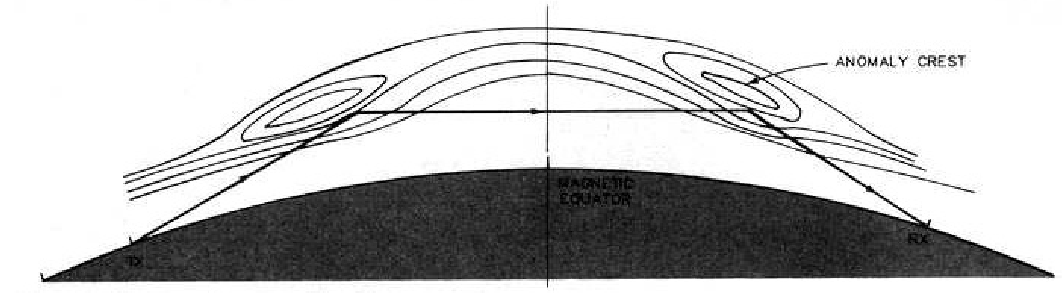

Figure 9.2. The "super" mode or FF mode of propagation believed to be responsible for afternoon-type TEP. Because of the upward tilt of the crest of the equatorial anomaly at the first reflection point, the radio waves travel directly across to the opposite crest without an intervening ground reflection. At this crest, the waves are reflected back down to earth at the receiver. The FF mode has a higher obliquity factor at each of its reflection points because of the tilts and can thus support higher frequencies than the normal 2F mode.

Transequatorial propagation (TEP) is the name given to propagation on circuits which cross the equator, more or less at right angles, which ususally have higher MUFs than the normal multihop modes. TEP was discovered by radio amateurs in 1947, but it is only recently that the propagation modes have been deduced. There are two types of TEP which rely on different features of the equatorial ionosphere for their support and which have different charac_teristics. These are called afternoon-type and evening-type TEP, according to the time of day when they occur. TEP has been observed regularly between the Mediterranean countries and southern Africa, between Japan/Korea and northern Australia, and between Central and South America. It has been found that it is the magnetic equator (see Part 4) and not the geographic equator which is important in determining what circuits will support TEP modes.

Both types of TEP have been observed simultaneously on some circuits, at around 2000 local time. Experiments in Australia by radio amateurs have shown that for locations in northern Australia, northern Japan transmitters (on Hokkaido) can be heard on 50 MHz during the day and southern transmitters (on Okinawa) can be heard during the evening. Transmitters in central Japan can be heard most of the afternoon and evening.

Afternoon-type TEP

Afternoon-type TEP has the following characteristics:

(1) An MUF greater than the normal 2F MUF, i.e: greater than 40-50 MHz.

(2) A peak occurrence at around 1700 to 1900 local time, near the equinoxes and around solar cycle maximum.

(3) Path lengths of 6000 km and sometimes longer.

(4) Normally strong, steady signals with a low fading rate and a small Doppler spread (which means that the reflecting layer does not move much).

It has been established that the propagation mode for these signals is a "super mode", or FF mode, in which the signals are reflected twice by the F layer, on opposite sides of the equator, without an intervening ground reflection. This is illustrated in Figure 9.2. The super mode relies for its support on the particular electron density distribution which exists in the vicinity of the magnetic equator. As can be seen from Figure 4.10, the electron density distribution in the equatorial regions has maximum values (called "crests") at about 15 degrees dip angle north and south of the magnetic equator, while the height of the maximum electron density, hmF2, has minimum values at these points and a maximum

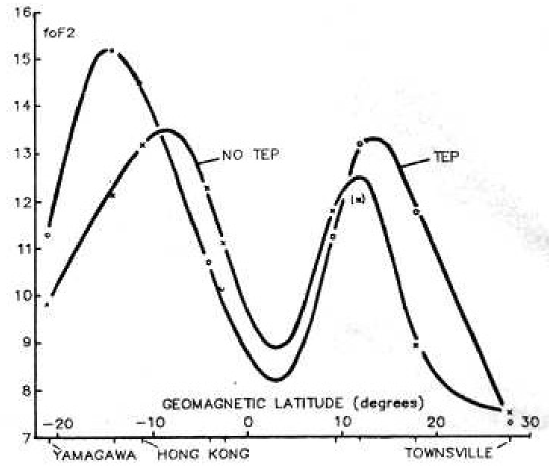

Figure 9.3. The variation of foF2 along the Yamagawa to Townsville circuit for selected days in August 1970 for which the FF mode existed (TEP) or did not exist (NO TEP). The maximum values of foF2, which correspond to the crests of the equatorial anomaly, are seen to be higher in frequency and further from the geomagnetic equator on those days for which TEP was observed. This is especially true for the northern peak for this month. The distribution is more symmetric with respect to the magnetic equator during the equinoxes. The ionospheric stations marked are Chung Li, Hong Kong, Manila, Bangkok, Singapore, Vanimo and Port Moresby.

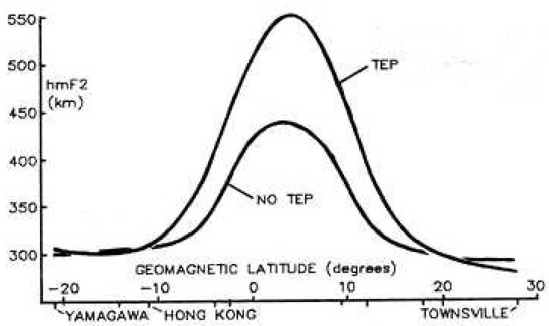

Figure 9.4. The variations with geomagnetic latitude of the height of the peak of the F2 layer, hmF2, for the conditions described in Figure 3. The main difference between the two curves is that the peak of the F2 layer over the equator is significantly higher on those days for which TEP was observed.

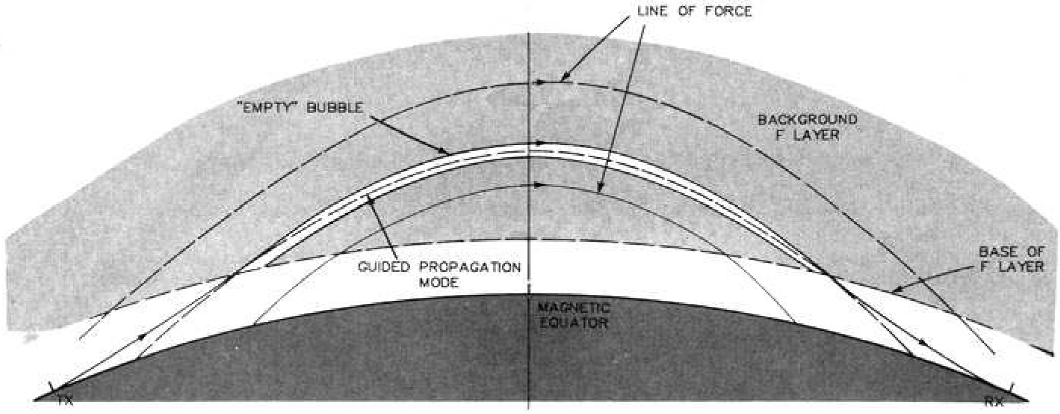

Figure 9.5. Sketch of a field-guided propagation mode which is believed to be responsible for evening-type TEP on many circuits. Hollow "bubbles" are formed just after sunset as the F layer rises rapidly, and diffuse quickly along the lines of force of the earth's magnetic field, yielding a family of field-aligned "empty" tubes embedded in the background ionosphere. VHF signals entering these tubes from favourable transmitter locations are guided around the tubes in a type of whispering gallery effect. The high frequencies supported by this mode are made possible by the large angle of incidence which the signals make with the walls of the tube — the ray path is nearly tangential to the walls — with a correspondingly high obliquity factor. At any one time, the transmitter and receiver may be linked by any number of bubbles which, because of their rapid rise through the F region, impose a range of Doppler shifts on the received signals.

over the magnetic equator. It is thus possible for a ray leaving a suitably placed transmitter to be reflected from the first crest in such a direction as to miss the earth and strike the ionosphere at the opposite crest and thence be reflected back to earth. Such a propagation mode would have an MUF higher than the normal 2F MUF because the ionosphere at the crests is tilted upwards towards the magnetic equator and gives rise to larger angles of incidence, and consequently larger obliquity factors and MUFs. The MUFs are also high because the critical frequencies, foF2, are so high in the crests.

Maximum observed frequencies for the super mode regularly exceed 50 MHz, where they have been observed in the 50 MHz or 6m amateur band, and have been known to exceed 60 MHz. The high signal strengths associated with super modes are readily explained in terms of focussing effects clearly exhibited in raytracing studies. Signals from a large range of elevation angles at the transmitter arrive at the receiver, rather than from just one particular elevation angle, giving higher than average field strengths. The signals also pass through the absorbing D region only twice, as against four times for a 2F mode, and are thus less attenuated.

The super mode does not exist every day, even during the times of its maximum occurrence — the equinoxes at solar maximum. Whether or not it appears on a given day depends on how the crests of the equatorial ionosphere have developed on that day. The crests must be high and well separated before they will support the super mode of propagation. This is also the reason the super mode exists for only part of the day, mainly the late afternoon and early evening, in spite of the fact that the crests themselves exist for a much larger part of the day. Figure 9.3 and 9.4 illustrate the variation of foF2 and hmF2 along the Yamagawa to Townsville circuit for selected days in August 1970, when TEP was observed or not observed.

The super mode is a very useful mode when it exists, offering strong, slowly fading signals at frequencies well clear of the congested HF spectrum. However it has not yet been possible to evolve a reliable prediction scheme which would allow an HF communicator to switch to the higher frequencies with confidence of finding a super mode present.

Evening-type TEP

Like the afternoon-type TEP, evening-type TEP relies on a feature of the equatorial ionosphere for its support. (This is why TEP is confined to transequatorial circuits — the appropriate conditions do not exist on mid-latitude and high-latitude circuits.) However, evening-type TEP generally supports much higher frequencies than the afternoon type and has very different characteristics:

(1) A peak occurrence at around 2000-2300 local time, near the equinoxes and around solar maximum.

(2) High signal strengths but with deep and rapid fading, with rates up to about 15 Hz, and a large Doppler spread which sometimes exceeds 40 Hz.

(3) Path lengths usually shorter than for the afternoon-type mode, being about 3000-6000 km.

The propagation mode for evening-type TEP is probably a whispering gallery, or "field-guided" mode. Experiments in the last decade have shown that at times when the evening-type TEP is observed, the equatorial ionosphere is threaded by "empty" tubes which are aligned along the field lines of the Earth's magnetic field and in which the electron density is much lower than that of the surrounding ionosphere. This is illustrated in Figure 9.5. Propagation is assumed to take place by the rays skidding around the top wall of the tube, being reflected several times off this wall, and then emerging at the far end of the tube.

Maximum observed frequencies (MOFs) in excess of 100 MHz were regularly observed between Darwin (Australia) and Yamagawa (Japan) before Cyclone Tracey put one too many twists in the receiving antennas at Darwin. During the past solar cycle (21), radio amateurs extended the observed MOF to 432 MHz; many evening-type TEP contacts were made on the 144 MHz 2m amateur band.

The very high MOFs arise from the very high angles of in- ▶

cidence, the rays just grazing the walls of the empty tubes. The large Doppler shifts are caused by the general upward movement of the tubes, which rise rapidly through to the top of the ionosphere after their creation near its base. The best circuits for this type of TEP are those for which rays can enter the tubes in a direction parallel to their axes, or, in other words the rays from the transmitter should be tangential to the earth's magnetic field at the altitude where the rays enter the tube. To achieve the highest MUFs, the receiver should be similarly placed with respect to the earth's magnetic field, which means that the circuit should be symmetric with respect to the magnetic equator. Darwin and Yamagawa are ideally placed for evening-type TEP, but are generally too close for afternoon-type TEP.

Evening-type TEP also remains essentially unpredictable on a night-to-night basis.