Tropospheric Scatter Techniques for the Amateur

An Examination of the Potential of Tropospheric Scatter Communication at 144 Mc. and Up

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THE WORD SCATTER is a fairly recent addition to the radio dictionary. It describes a new technique of point-to-point propagation that has revolutionized the old concepts of communication. Admittedly, scatter has been a controversial subject among scientists, even those who have been working with it for some years. Thus, adaptation of scatter techniques to amateur communication may well offer us further opportunities for contribution to the advancement of the communications art.

Actually there is nothing really new about this type of transmission. Amateurs have been using forms of scatter for years, though, unfortunately, not many of us recognized what was going on at the time. For this reason it might be well to explain just what scatter is, in plain and simple language, and to show how we can make use of it in amateur v.h.f. communication.

Two of the most common concepts of communication are shown in Fig. 1, drawn on an arc that represents the earth's curvature. The first is

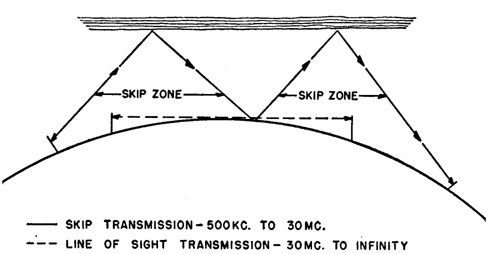

Fig. 1 — **Two principal forms of propagation are skip, which involves reflection from an ionospheric layer, and line-of sight, which is essentially a local-communications medium.**

called skip transmission. It is used for communication over distances from under one hundred to several thousand miles, and on frequencies from 500 kc. to 30 Mc. It involves reflection of the wave from one or more of the ionospheric layers far above the earth's surface.

The second is known as line-of-sight transmission. It is the means of short-distance communication on frequencies from about 30 Mc. up. Normal reliability for commercial use is predicated on transmission paths of about 40 miles, over open terrain, where it provides very strong steady signals with low power. Even though line-of-sight transmission was once supposed to be the ultimate in reliability at such a distance, ducting, refraction and magnetic disturbances cause blackouts to the degree where over-all reliabilities above 90 per cent are rare. Where extreme reliability is required, neither line-of-sight nor skip transmission can be depended on entirely.

In the process of observing the peculiarities of line-of-sight transmission, unexplained high signal levels were received consistently at distances far beyond the horizon. These signals could not be traced to tropospheric bending, ducting, knife-edge refraction, or to *E*- or *F*-layer skip. This ability to work well beyond the theoretical limit of v.h.f. propagation was also well known in amateur v.h.f. circles. Studies were made of many such observations, and from these Dr. Booker and Dr. Gordon of Cornell University evolved the theory of v.h.f. scattering.[1] Trial and error experimentation has substantiated the Booker-Gordon theory, in large part.

Forms of Scatter

There are two general types of scatter transmission. One is known as *forward propagation tropospheric scatter* and the other as *forward propagation ionospheric scatter*. Both are often referred to as *beyond-the-horizon transmission*. Much has been written about ionospheric scatter in *QST*,[2] so it will not be dealt with here. I will, however, differentiate between the two, and show methods by which tropospheric scatter systems may be set up on 144 Mc. and higher frequencies. From the calculations systems may be planned for any frequency above about 100 Mc.

Ionospheric scatter is useful mainly for distances of 600 to 1300 miles, and on frequencies in the 25–70-Mc. region, with bandwidths of less than 50 Kc. The bandwidth restriction is the result of multipath propagation, which results in the selective fading distortion so well known on lower frequencies.

As its name implies, tropospheric scatter makes use of eddies in the troposphere[3] to accomplish bending. Frequencies all through the v.h.f. range, and up to infinity can theoretically be used. Most present usages are in the 400–1000-Mc. range,

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[1] Booker and Gordon, "A Theory of Radio Scattering in the Troposphere," *Proc. IRE*, April, 1950, p. 401. The theory was interpreted for amateur readers by Moore, "Over the Hills and Far Away," *QST*, Feb., 1951, p. 13.

[2] Moynahan, "V.H.F. Scatter Propagation and Amateur Radio," *QST*, March, 1956, p. 43.

[3] Tropospheric scattering masses are actually more complex in structure than this simple definition implies. For readers seriously interested in ionospheric and tropospheric scattering masses, the "Scatter Propagation Issue" of *IRE Proceedings* is recommended (Oct., 1955).

with some work having been done at lower and higher frequencies.

Recently the trend has been to frequencies in the lower 300-Mc. region. Bandwidth is limited, theoretically, to a maximum of four or five megacycles, but in practice it has been extended to as much as 20 Mc.[4] In general, distances up to 400 miles or so can be covered with a well-designed system, but there is reason to believe that this is not the practical maximum, and that ranges may eventually be extended to 1000 miles or more.

How the tropospheric scatter signal is propagated is shown in Fig. 2. In effect, the primary wavefront passes through an area of the atmosphere that is turbulent. This turbulence can be

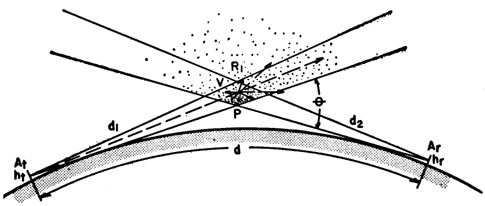

Fig. 2 — **Tropospheric scattering takes place when the radiated wave enters a region of atmospheric turbulence. The energy is scattered in all directions, a small portion returning to reach well beyond the visual horizon.**

likened to the eddies in a moving stream. The energy is reradiated in all directions (arrows) in the area of turbulence, and a small part of it is returned to the earth at points far beyond the visual horizon. The effect is not unlike that of a sharp light beam entering fog or smoke.

Planning a Scatter System

A typical scatter communications system is shown in Fig. 3, which gives the factors that must

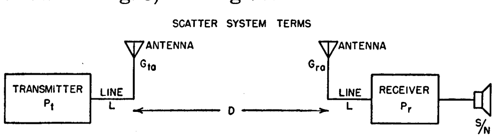

Fig. 3 — **Typical scatter system, and definitions of terms involved in its effectiveness.**

P_t — Transmitter power above 1 watt, in db.
G_{ta} — Transmitting antenna gain, in db.
D — Distance between antennas, in miles.
G_{ra} — Receiving antenna gain, in db.
L — Losses in transmission lines, in db.
P_r — Input power to receiver below 1 watt, in db.
S/N — Signal-to-noise ratio, in db.

be taken into account in determining its effectiveness. These include the transmitter power, antenna gains at both ends of the system, the line losses in the antennas, the distance between them, the power input to the receiver, and the signal-to-noise ratio. Also required are the system bandwidth and the receiver noise figure.

These terms are largely self-explanatory, with the exception of the input to the receiver, P_r, which is determined from

$$P_r = KTB - NF - (S/N)$$

[4] Bell System Miami-to-Havana Link.

where KTB is the thermal noise, expressed in db. below one watt, NF is the receiver noise figure in db., and S/N is the signal-to-noise ratio in db.

With the use of these terms the performance of a scatter communications circuit can be predicted with a fair degree of accuracy. Let us assume that we want to set up a scatter system on 144 Mc. We have a transmitter delivering 200 watts of power, transmitting and receiving antennas with gains of 10 db. each, and line losses totalling 4 db. over-all. We feel that a 10-db. signal-to-noise ratio will be adequate. The receiver will have a noise figure of 6 db., which is readily obtainable at 144 Mc. All the factors given in Fig. 3 are now available, so we can find the distance over which this combination will operate satisfactorily.

Calculation of the receiver input power, P_r, is greatly simplified by the determination of the factor KTB from the Table below. Thermal noise is

Bandwidth:	100 Mc.	10 Mc.	1 Mc.	100 kc.	10 kc.	1 kc.
KTB in db. below 1 watt:	124	134	144	154	164	174

directly related to bandwidth. If the bandwidth is one megacycle, KTB is approximately 144 db. below one watt. If the bandwidth is decreased ten times, the value of KTB increases by 10, and so on. For amateur work, a bandwidth of 10 kc. is certainly more than adequate. From the table, we see that this bandwidth will yield a KTB of 164 db. below one watt. The receiver input power is thus

$$P_r = KTB - NF - (S/N)$$
$$= 164 - 6 - 10, \text{ or}$$
$$148 \text{ db. below 1 watt.}$$

Our transmitter power output, 200 watts, is 23 db. above 1 watt. Transmitting and receiving antennas add 10 db. each, for 20 db. more. Line losses subtract 4 db., leaving a total system gain of 187 db. This system gain may then be used in the nomogram, Fig. 4, to determine the distance over which it will work. The figures in the middle column of the nomogram are propagation losses for free-space scattering between isotropic antennas. By laying a straightedge at the frequency, 144 Mc., right, through the 187-db. loss point, we find that 180 miles is the approximate distance over which our equipment will cover in communication by tropospheric scattering.

It should be noted that there are other gains and other losses that must be taken into account before a really accurate estimate can be made of the nature of a scatter path. One gain results from the fact that the nomogram is based on isotropic antennas; therefore another 2.3 db. gain can be assumed if our antenna gains were in reference to half-wave dipoles. A possible loss results from the presence of galactic or manmade noise, neither of which is included in the calculations. Coupling and line losses may be difficult to determine accurately in amateur installations.

These are known in engineering circles as

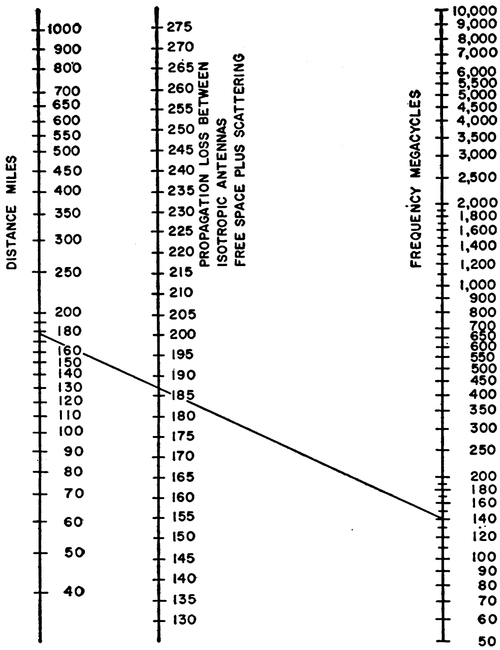

Fig. 4 — **Nomogram for estimating performance of a scatter circuit. Slanting line represents example given in text.**

"fudge factors" — items that are difficult to measure accurately, but which can affect the results of any system planning appreciably if they happen to add up in one direction or the other.

Now we have other contingencies sneaking up on us. Fig. 5 shows what may be expected in the way of signal variations, with regard to percentage of time. This is commonly referred to as a reliability curve. It shows the percentage of total time that any given median level will be exceeded. As can be seen, the signal level will be at least 6 db. above the predicted value 10 per cent of the time. It will be no more than 8 db. below the predicted value 90 per cent of the time, and no more than 38 db. below the predicted value 99.99 per cent of the time. From this curve we can see what needs to be added to the figure we got from our nomogram, if we want very high degrees of reliability. Amateurs are seldom concerned with such reliability, so the discouraging figures shown for the reliabilities greater than 90 per cent need not worry us.

Reliability better than 50 per cent is probably rare in amateur communication, but if we want to go up to the 90 per cent figure, we need only pick up another 8 db. somewhere in our circuit. There are many ways by which this might be done. Power increases, higher antenna gains, improved receiver noise figure, and the employment of diversity techniques are some of the means by which reliability on experimental v.h.f. scatter circuits have been pushed to the almost infinite figure of 99.999 per cent.

In the example given, we could pick up at least 5 db. through increasing power to the legal limit. We might get 4 db. more at each end by antenna improvements, for a total of 8 db. Going to single-side-band techniques could yield another 9 db. Doing all these things would net us 22 db., and push our reliability up to well over 99 per cent. Or it would extend our transmission distance, with the previous reliability, out to nearly 350 miles. Going to diversity techniques, a step beyond most amateurs' capabilities, could push the effectiveness of the system out still further. Use of narrow-band reception and c.w. transmission with high stability are possibilities that should not be overlooked.

The expected signal level of Fig. 5 includes all the common types of signal variations, such as:

1) *Scintillations* having a time duration of the order of one to ten cycles per second. These are seldom less than 5 db., and may be as much as 25 db. These may be nearly eliminated by the use of either space or frequency diversity. Audio filters in the output also may greatly reduce the effects of scintillations on intelligibility.

2) *Diurnal Fluctuations* ranging from 5 to 10 db. from day to night are fairly common. These should be allowed for if reliable communication is needed over a 24-hour daily schedule, but they can often be avoided in amateur scheduling.

3) *Seasonal Variations* may provide as much as 20 db. more signal in summer than in winter, in middle latitudes. This can be represented as 10-db. improvement with respect to the median of Fig. 5. Up to 15-db. improvement over the

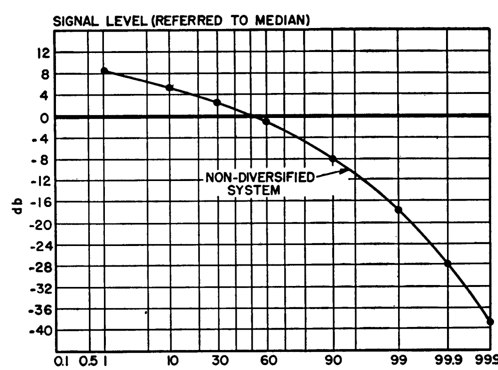

Fig. 5 — **Reliability curve for a scatter communications system without diversity techniques.**

values in Fig. 4 appears to be realizable in tropical areas like Southern Florida, during most of the year. The latitude of South Carolina should add 5 to 10 db. The values are approximate for the latitude of New York, while upper Canada would have to subtract about 10 db.

Antennas

Using double or triple diversity reception will nearly eliminate scintillations, as well as provide 2 to 4 db. more signal. Space diversity might be applicable to some amateur installations. It involves two or three antennas spaced at least 6 wavelengths center to center, a combiner or switcher, and two or three receivers.

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Office will only entertain the listing of 75-meter mobiles. If any of you are mobile, with or without unrestricted telephone privileges, please let either FB or myself know. SH is on again with a new transmitter, DH is "hoop-de-dooing with good contacts on s.s.b. BF is busy but DXing. AQB is on fairly regularly. AOG is on with RTTY. ALL is back with a potent signal seemingly no worse for wear. GR is having beam trouble. Try 2-meter insulators, Phil. ARZ is going 2-meter mobile. AIO now is on with a DX-100 and a signal. ARX, Father Oscar Dietz, is one of the new amateurs who, though blind, faithfully stuck to the grind and got his ticket. Congrats. Other new calls of the VARC are AHT, APX, AUA, OC and VX, all through the classes held by XW and AQW, who should be congratulated for their untiring efforts in helping and training others to get their tickets. We think it is about time Vancouver had a National Convention. Is anyone willing to help undertake such a task? Toss the idea around, anyway, something might come of it. Traffic: VE7DH 14, ASR 9.

Tropospheric Scatter Technique

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Now a word about antenna height and siting. The antenna should be aimed at the horizon, or slightly above it. Antennas at both ends of the path should be of the same polarity. For a given frequency the center of the antenna should be a certain optimum height above ground, given by the formula

$$H = 4000\frac{\lambda}{d}$$

where λ and H are in the same units and d is the distance in miles.[5] Working this out for 144 Mc. ($\lambda = 7$ feet) gives 155 feet as the optimum height, a value most 2-meter men would find hard to achieve. However, the difference between this optimum and a mere 10 feet off ground is only 6 db.

If you work with this formula, you will see that as the path length is increased the optimum height for a given frequency becomes less, and as the frequency goes higher the optimum antenna height is lower. For amateur v.h.f. work, I would suggest putting the antenna as high as possible, and clear of all obstructions. Particularly if the latter condition is satisfied, the difference in results between practical heights and the theoretical optimum may be small.

It is quite possible that at 144 Mc. and lower frequencies, the signal received at distances out to 150 miles or so may be larger than predicted. This is because the refracted signal may be as strong as the scattered signal. Hence they may add at the receiver.

Gains in antenna can be traded for transmitter power up to the point where the beam widths in the horizontal and vertical planes approach 3 to 4 degrees. Beyond this point, the antenna coupling to the reflecting mass area decreases. In essence, this means that not enough of the area is being excited, hence the ratio of the received signal is less than with a wider beam.

Effective gain is not proportional on a swap basis if the physical area becomes excessively large, either. It will probably be found that a large rhombic will not be as effective as the Yagi

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[5] For frequencies above 500 Mc., change the figure 4000 to 5000.

type of array, even though the main beam gain, in the near field, is the same. This is the result of cancellation by out-of-phase components in multipath propagation, a condition that is even more marked in ionospheric scatter work.[2]

The Threshold of Discovery

There is reason to believe that beyond a 400-mile distance the signals of a tropospheric nature are no longer scatter signals in the strictest sense of the word. It is the author's belief that distances out to 1000 miles can be covered by the use of techniques similar to those presented here. A real contribution can be made in this comparatively little-known area by radio amateurs using c.w., single side band and other narrow-band transmissions. (Bandwidth can be traded for power.)

What can we expect from scatter? Depending upon the care with which equipment is set up and operated, consistent and reliable contacts should be possible out to at least 300 miles. With very large arrays (but still within the reach of the ambitious v.h.f. man), high power, and the best possible receiving equipment, consistent contacts should be made out to well over 400 miles. The beautiful part about a scatter circuit is that once it is established on a sound basis, you never lose contact because of fade-outs that ruin communication on lower frequencies. When conditions are at their worst in other types of communication, scatter signals are usually at their best.

For emergency communication, a city-to-city amateur scatter network on 144, 220 or 420 Mc. should provide the ultimate in reliability, plus maximum security. The serious traffic-minded amateurs should consider scatter. And as a means of developing interest in a v.h.f. band, in an area where it is now low or nonexistent, employment of scatter techniques may be just what you've been looking for.

Try it!