Meteor-Scatter Communication Statistics: Theory vs. Practice

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Abstract

Presented here are the results of a lengthy effort to collect received MSK-144 meteor-scatter decodes and compare these experimental results to theoretical predictions. Decode SNR's from three particularly active stations were individually averaged. Theoretical models for each station were created in Excel to allow for comparison with the experimental data. The theoretical model, created in an Excel spreadsheet, was based primarily on the sentinel 1997 ITU paper "Communication By Meteor-Burst Propagation" (Reference 3). **Comparisons of the theoretical predictions and averaged experimental data support high confidence in the theoretical model.** With the curve of decode probability vs. SNR (Fig. 6 in Reference 2), predicted signal SNR's can be converted to predicted decode probabilities, thus allowing for point-to-point meteor-scatter link communication planning a step above just "hoping to get lucky".

Meteor-scatter Basics

Communication by reflecting radio signals off of ionized meteor trails dates back to the early 1950's when various national defense organizations began serious theoretical and experimental studies of the radio reflection properties of micro-meteor ionization trails. In **1957**, NATO held a meeting where research papers on the theme "The Use of Meteors in Communications" were presented. **The opening paper, "Forward Scattering from Meteor Trails", laid out the entire theory of meteor scatter physics in just four pages (Ref. 5).**

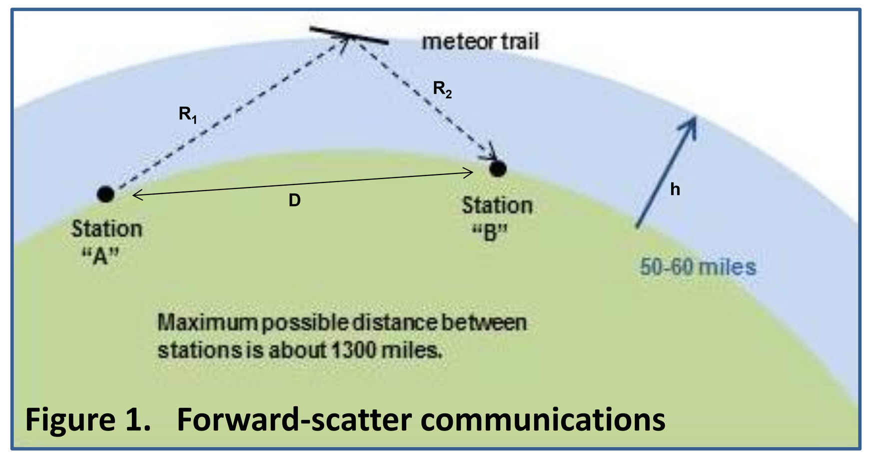
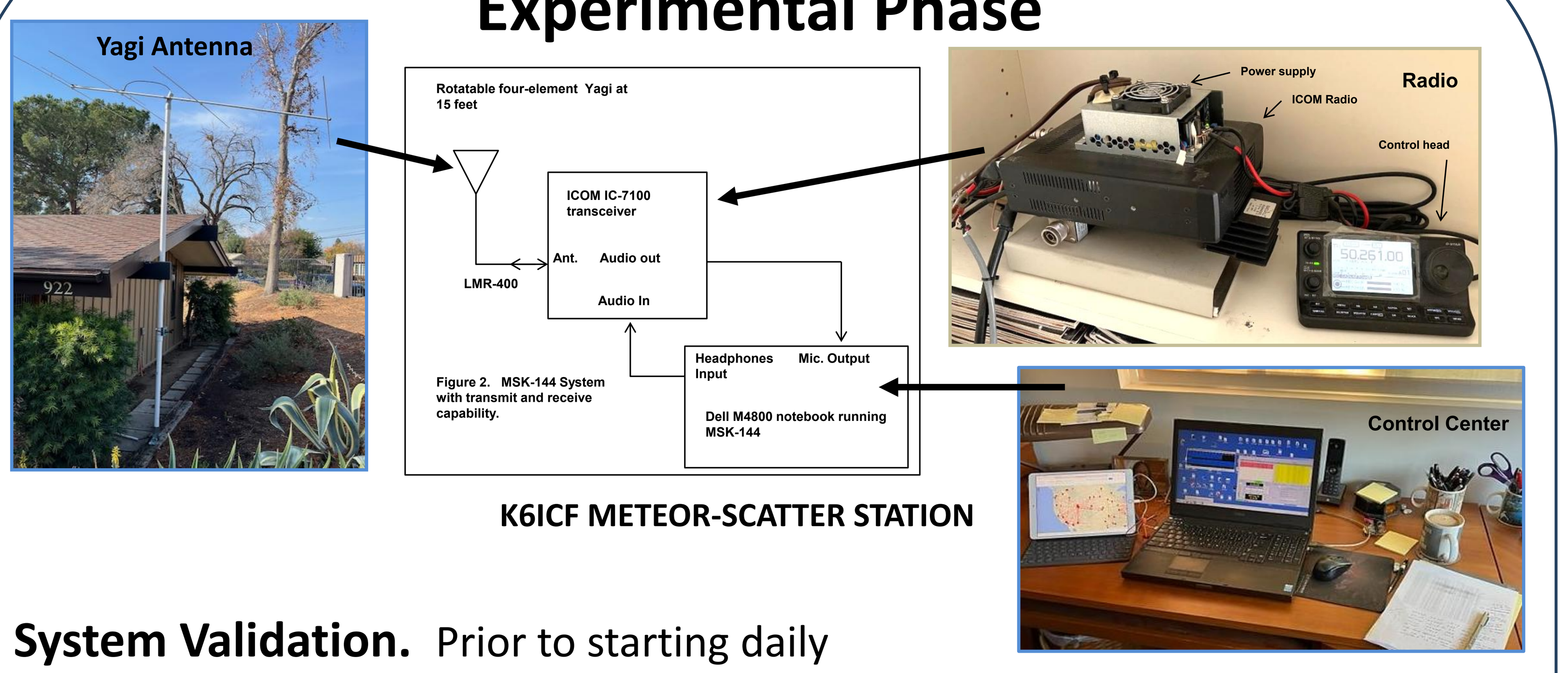


Figure 1. Forward-scatter communications

Figure 1 (left) is a pictorial of a meteor scatter path between two stations. The maximum distance possible is limited by the curvature of the earth and is given by the equation D = 177.3 x sqrt (h) where D and H are in miles. This is actually a 3D picture as the meteor trail can be some distance to one side or the the other of a line connecting "A" and "B". The only real requirements are that the trail must be "between" the stations (for forward scatter) and within line of sight of both. Think of it as if "A", at ground level, is sending a signal to a repeater with a really tall antenna height (h) which then forwards a **much-attenuated** version of the signal down to "B" which is also at ground level. The total signal power loss from "A" to "B" is the sum of the space loss due to the distance, $R_1 + R_2$ plus the scattering loss due to the signal being reflected off the meteor trail, a poor reflector.

Experimental Phase



K6ICF METEOR-SCATTER STATION

System Validation. Prior to starting daily operations, the system was tested using an MSK-144 signal simulator consisting of a laptop pc running WSJT-X and pretending to be a transmitter. The audio output was used to modulate the output of a Fluke 6060B RF signal generator at 50.260 mHz. The output level could then be accurately set to create an MSK-144 signal at any desired SNR. Decodes down to -7 dB were observed and decodes at higher SNRs were consistent with the probability curve in Ref. 2 Fig. 4. Antenna LMR-400 feedline loss (0.3 dB)and system SWR (1.2) were measured with a VNA.

Data Collection Phase (2/18/24 to 8/11/24). The station was set-up so that it could be run unattended during the early morning hours monitoring the six-meter MSK-144 calling frequency (50.260 mHz). All MSK-144 decodes were automatically logged to the WSJT-X perpetual **all.txt** data file. Late in the day, the antenna would be rotated to the desired azimuth angle for the following day's operation. The station was run for a total of 138 hours over 50 days, recording decodes from 79 stations at distances up to 1114 miles. Decodes from local stations were excluded. Abundant decode sample sizes were obtained from three particularly active stations, **KE4TH in UT, W0XR in AZ and W7OOU in ID,** who supplied important details about their stations needed for later analysis. Editing was required to throw out duplicate decodes (where more than one decode was obtained from a single meteor trail) and to add decodes to the data set to compensate for the effect of reduced decode probability at low SNR's. Results are summarized in **Results and Conclusions** at the end of this poster.

Theoretical Phase

Theoretical models were created in Excel producing predications that can be directly compared to the experimental data.

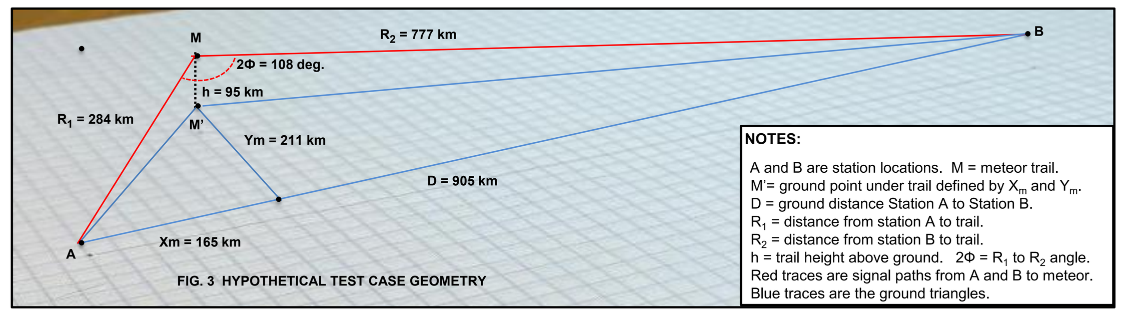


Figure 3 above shows the geometry of a typical meteor scatter path between stations at A and B. The equations for scattering loss as presented in Ref. 3 were simplified and combined as shown in Figure 4 for creation of the Excel spreadsheet shown in Figure 6.

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Theoretical Phase (cont.)

Figure 4, below, is a simplified, but accurate equation for scattering loss.

$SL = (K_1 * A_1 * (R_1+R_2)) / (R_1*R_2*G)$ where $A_1 = \exp(K_2 * \cos^2 \Phi)$. K_1 and K_2 are constants for a given λ and $G = (1 - \sin^2 \Phi * \cos^2 \beta)$.

β, the angle between the meteor trail axis and the plane of propagation (A-M-B), can take on any value from 0 to 90 degrees with equal probability for any particular trail. Thus, an average value for G must be calculated to include this range.

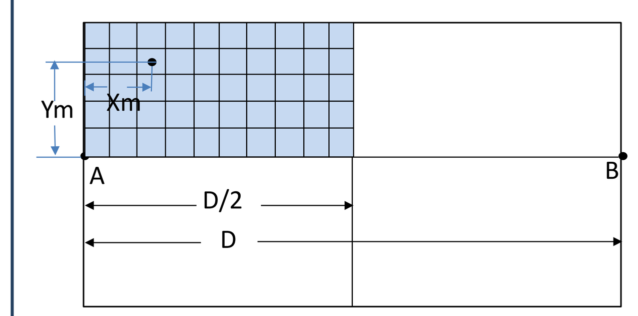

Figure 5. Receive Area Matrix

Figure 5 shows the receive area between two stations (A and B) broken down into four quadrants. Due to symmetry, the SNR for only one quadrant needs to be calculated such as the blue area in the diagram. This area is divided into 50 squares and an SNR for the center of each square is calculated by a line in a 50-line, 44 column Excel spreadsheet, which is far too large to be included here. These 50 SNR's can then be averaged to produce a single number representing the average SNR for the entire receive area. This value can, in turn, be compared to experimental measurements of decode SNRs between the two stations. In Figure 6 below are a few lines of the spreadsheet in highly abbreviated form.

Figure 6. Condensed spreadsheet

GEOMETRY									ANTENNA GAINS								SNR CALCULATIONS							72ms.
Km Xm	Km Ym	Km D1	Km D2	Km D	Km C2	Km R1	Km R2	deg Ø	Max Gain	θh H error	dB H loss	dB Net Gain	Max Gain	θh H error	dB H loss	dB Net Gain	dB SL	R1+R2 FS loss	Total loss	dB(mw) Tx	Total ant. gain	Rcvd. power	Noise dB(mw)	Ave. SNR dB
25	25	25	292	317	293.1	101.4	308.1	42.8	10.4	35.0	3.0	-109.3	15.7	35.0	7.6	1.7	-49.2	-118.7	-167.9	58.1	-107.5	-217.3	-122.1	**-98.8**
25	75	25	292	317	301.5	123.6	316.1	39.6	10.4	35.0	3.0	-40.2	15.7	35.0	7.6	2.4	-49.6	-119.3	-168.9	58.1	-37.8	-148.6	-122.1	**-30.4**
25	125	25	292	317	317.6	159.0	331.5	35.4	10.4	35.0	3.0	-10.0	15.7	35.0	7.6	3.6	-50.0	-120.2	-170.3	58.1	-6.4	-118.6	-122.1	**-0.8**
25	175	25	292	317	340.4	200.7	353.4	31.4	10.4	35.0	3.0	1.3	15.7	35.0	7.6	4.8	-50.5	-121.3	-171.8	58.1	6.1	-107.5	-122.1	**10.0**
25	225	25	292	317	368.6	245.5	380.7	28.0	10.4	35.0	3.0	5.5	15.7	35.0	7.6	6.0	-50.8	-122.4	-173.2	58.1	11.5	-103.6	-122.1	**13.7**

Results and Conclusion

	KE4TH	W0XR	W7OOU
Number of decodes:	**276**	**446**	**142**
Measured SNR Average:	**6.1 dB**	**7.6 dB**	**5.2 dB**
Theoretical SNR Average:	**5.5 dB**	**8.0 dB**	**4.8 dB**

Conclusion: Comparisons of the theoretical predictions and averaged data support high confidence in the theoretical model developed for this project.

References

1. McKinley, D.W.R., 1961, *"Meteor Science and Engineering"*, McGraw-Hill
2. Franke, Steven J., K6AN and Taylor, Joseph H., K1JT *"The MSK144 Protocol for Meteor-Scatter Communication", QEX July/August 2017*
3. ***ITU Recommendation ITU-R P.843-1 "Communication by Meteor-Burst Propagation (1992-1997)***
4. Haakinson, E.J., Feb. 1983, NTIA Report 83-116 *"Meteor Burst Communications Model"*
5. AGARDograph26, July 1957, *"Forward Scatter Communication Via Meteor Trails and Related Problems"*

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