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White Paper

Practical Radio Use

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Purpose: I have observed that many military & civilian radio users do not have a good understanding of the factors affecting radio performance. I have encountered helicopter units that had only one authorized HF frequency - which resulted in unreliable comm. I've noticed that many pilots don't adequately account for radio theory in their operations. For example, aircrews often don't distinguish between the upper & the lower antenna but use them interchangeably. Also, you will often find unnecessary radio problems in histories of military operations, revealing that inadequate attention is given to the best ways to use radio. You can see the same problems in the civilian world, but the military scenario is usually more pronounced for several reasons. For instance, a true battlefield situation usually involves a greater amount of interference and traffic than exercises.

Therefore, I am writing this opinion paper as a brief introduction to some basic ideas related to radio performance and the use of radio. Radio performance is subject to many variables beyond the user's control, but maximizing the basics will partially compensate for these environmental variables. I do not get into the technical aspects of radio theory except what is needed to use radio wisely.

I have divided this discussion into three broad categories of radio used for communication: HF, satcom and line-of-sight. The last section discusses recent improvements and gives an example of a newly developed radio. But first here is a discussion of the three modes of signal propagation.

Typical Uses. There are many examples of different types of radio communications that use each of the three modes of signal propagation. The list that follows is merely representative of some of the more common examples. **The critical factor is frequency; ground wave is only efficient up to 2 MHz, and sky wave is only possible below 30 MHz.**

Ground Wave: submarine communication, maritime radio, daytime commercial AM broadcasting.

Sky Wave: nighttime AM broadcasting, amateur radio, log-distance aircraft communication.

Line-of-Sight: commercial FM radio, broadcast television, VHF comm, UHF comm & radar.

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1. HF Radio (over-the-horizon): HF radio has long range, but it requires some knowledge to operate reliably. This is because HF propagates partly by means of a “sky wave”. The sky wave reflects off the ionosphere & off the earth. Correct use of the sky wave requires choosing the best frequency based on the present state of the ionosphere and on the distance over which you are communicating. Here are some quotes:

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>>A HF signal transmitted from the earth may travel some way through the ionosphere before being "bent" back down towards the ground. This occurs due to the interaction between the HF signal and electrically charged particles in the ionosphere. The signal can then "bounce" off the ground back into the ionosphere, return to the earth again, and so on. The distance a given HF signal will travel depends on the frequency, transmitter power, take-off angle relative to the ground and the state of the ionosphere through which it is travelling.

For any given distance and time, there will be a certain range of HF frequencies that are most likely to provide successful communications; frequencies outside that range will work poorly or not at all. Simply increasing the power of a HF signal will not help if the frequency is too high for the distance required. Increasing the power may help if the frequency is too low, but using a higher, more suitable frequency is the best option. The highest frequency, which may be used for reliable HF communications, is known as the Maximum Usable Frequency (MUF). <<

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Radio propagation at HF frequencies

In HF bands, reliable use can be made of both ground and sky wave energy components, allowing communications over short and long ranges.

HF radio equipment typically provides the operator with a selection of frequencies in different bands. This allows the operator to select a frequency that will be suitable both for the distance over which communications are required, and the time of day and season. The lowest frequency that will provide effective communications should be selected first. This has the effect of minimizing the distance that the radio waves will travel and reducing interference to other HF users.

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The HF radio used by the AF, the AN/ARC-190(V), has some features, which solve the problems of frequency selection. This radio has Automatic Link Establishment (ALE), which automatically selects the best usable frequency. It also has Selective Calling (addressing) and a net setup. These types of improvements should greatly improve the reliability, efficiency & quality of HF communications. There are also computer programs and many other resources that will help with frequency selection. A great deal of information and many services are available to amateur radio operators. [Note: Each AFB has a Frequency Manager who can assign frequencies. A unit needs a variety of HF frequencies for good comm..]

2. Satcom Radio: Satellite communications (Satcom) has many advantages:

- unlimited range
- possibly more secure (you only need to transmit up in the direction of the satellite)
- normally unaffected by terrain
- usually has worldwide coverage or nearly so
- should be reliable

Satcom has some disadvantages:

- requires an expensive satellite system
- must have sufficient power to reach the satellite
- satellites have limited capacity

Satcom systems vary widely. Many tradeoffs are made in the design of a satcom system regarding the type of satellite orbit, coverage, required power, & required antennas. Ideally, a system requires the user to have only a lightweight, handheld radio with a simple antenna. Some systems require a dish antenna to be aimed at the satellite.

3. Line-of Sight (LOS) Radio: LOS radio includes VHF, UHF, radar, etc. As the name implies, LOS radio works best on a clear line-of-sight. It will not reach beyond the horizon (or the radio horizon which is slightly further than the visual horizon). Here is a discussion of the radio horizon:

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Effective Earth radius: The radius of a hypothetical Earth for which the distance to the radio horizon, assuming rectilinear propagation, is the same as that for the actual Earth with an assumed uniform vertical gradient of atmospheric refractive index. [Note: For the standard atmosphere, the effective Earth radius is **4/3** that of the actual Earth radius.]

Radio horizon range (RHR): The distance at which a direct radio wave can reach a receiving antenna of given height from a transmitting antenna of given height.
[Note: The radio horizon range in **nautical miles**, R, is given by the relation $R = 1.23(h_t^{1/2} + h_r^{1/2})$, where h_t and h_r are the heights of the transmitting and receiving antennas in **feet.**]
[Note: The radio horizon range in **statute miles**, R, is given by the relation $R = 1.41(h_t^{1/2} + h_r^{1/2})$, where h_t and h_r are the heights of the transmitting and receiving antennas in **feet.**]
[The radio horizon range, R, in **nautical miles** is also given by the relation $R = 2.23(h_t^{1/2} + h_r^{1/2})$, where h_t and h_r are the heights of the transmitting and receiving antennas in **meters.** The effective Earth radius, **4/3 times the actual Earth radius, is used in deriving the formulae.** Second-order differentials are neglected. They are of the order of 0.1%.
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The visual horizon is a good conservative estimate for most purposes (on flat ground). It is important to note that terrain & other obstacles make a big difference. They can cause shadowing, attenuation and reflections (multipath). Therefore height is a key concern for LOS communication. Hence radio towers. This is also the reasoning behind satcom. You raise one antenna up into the sky eliminating these problems. For good LOS communications, look at these factors:

1. **Clear line-of-sight** - increase antenna height where possible, reduce distance & avoid obstacles.
2. **Interference** – requires good channel selection & radio discipline amongst users.
3. **Ensure effective radiated power (ERP) is per spec** – good antenna cables, antenna etc.

Cell phone users experience these same issues every day. The same rules apply. A clear line-of sight is based on height, distance & terrain/obstacles.

Antenna cable basics: Antenna cable is an important part of the antenna system and a frequent source of confusion. Antenna cable is a source of loss & distortion. Here are some general rules of thumb for cable loss:

1. The longer the cable, the greater the loss.
2. The higher the frequency, the greater the loss.

3. The smaller the diameter (of the cable), the greater the loss – generally but not always. (You should compare the specs.)

The following shows some typical examples for some common 75 Ohm cables. RG-6 and RG-59 are often used for cable television among other things. Note that a 3dB loss cuts your power in half, 6db = ¼, and so on.

CABLE ATTENUATION (Cable Loss Per 100') AVERAGE

CABLE TYPE	5 MHz	100 MHz	300 MHz	450 MHz	900 MHz	1450 MHz
RG-6	.65 dB	1.98 dB	3.38 dB	4.21 dB	6.14 dB	8.26 dB
RG-59/U	1.09 dB	2.60 dB	4.45 dB	5.440 dB	8.65 dB	10.0 dB

(Note that GPS operates above 1500 MHz.)

And another example:

Typical Coax Cable Technical Features

Code	RG 11	RG 6	RG 59
Nominal impedance Ohm	**75**	**75**	**75**
Polyethylene dielectric	Expanded	Exp.	Exp.
Outer PVC sheating O mm	6.6	6.7	6.2
Capacity pF/m	84	55	55

FREQUENCY VS. ATTENUATION

Frequency	Attenuation db/100m		
50 MHz	4.5	4.9	6.0
100 MHz	6.5	6.4	7.5
200 MHz	8.3	9.3	11.0
400 MHz	11.9	13.6	17.0
500 MHz	14.0	15.7	19.0
600 MHz	15.0	17.2	22.5
800 MHz	17.9	20.2	25.0
1000 MHz	20.1	22.9	28.5
1750 MHz	28.1	30.9	-
2050 MHz	30.6	33.8	-

Improvements to Look for in Radio Technology

Digital Radio: Generally speaking digital radio technology is superior in many ways to analog technology. It usually results in greater efficiency/capacity, better quality, more features and better reliability. Additionally, digital technology is more flexible allowing constant improvements to be added. It facilitates advanced digital signal processing. The Department of Defense (DoD) is working on software configurable multiband radios. These could be made compatible with many different radios/standards by means of the software (SW). Improvements would be done thru SW changes.

Spread Spectrum (SS): Spread Spectrum (SS) is the general term for a variety modulation schemes that include frequency hopping, direct sequence/code division multiplexing and various pulsed schemes. SS schemes are generally superior to other types. They are especially good for military applications because they are inherently covert & because they have inherent jam resistance. (jam resistance = interference resistance = less susceptible to interference)

Selective Calling (or addressing): Selective calling, which goes by various names, is simply an addressing scheme. Your cell phone uses an addressing scheme where your phone number is the address. Addressing directs a call to a specific radio. This allows your radio to let you know when a call comes in to you. It saves you from having to monitor a channel waiting for a call. It also works well with many other features. (You can still have "all calls" or distress call monitoring depending on the specific scheme.) Some complementary functions are weather alerts, automatic distress functions, automatic frequency selection and automatic power management. Addressing allows the radio to do a lot of things for you because it now knows who is talking to you & who isn't. It also knows to whom you are talking which allows the radios to exchange information. In addition to routing calls, addressing can give all types of other information and allows the exchange of data.

Power Management: Many new radios automatically adjust the power level to suit the situation. Mainly the power is reduced to the minimum necessary to maintain a good link. This saves power & limits interference in high traffic situations. This is usually implemented in selective calling/addressed systems. Most digital cell phones do this. The Traffic Collision Avoidance System (TCAS) for aircraft uses power management for interference limiting. Another form of power management is using steered antennas to focus power on the intended target and away from other areas. Of course, just halving the angular area of the beam doubles the power density. Therefore just reducing the beamwidth from 360 deg to 180 deg doubles the power to the target. Antennas can be mechanically steered or electronically steered. Electronically steered antennas use an array of small antennas, called antenna elements. These antenna elements interfere with each other in such a way as to steer a beam. A good example is phased array radar that is widely used in the military. TCAS uses an antenna array to achieve directional capability. That antenna array allows it to determine the bearing of other aircraft.

Encryption: Encryption is highly under-utilized, especially in the civilian sector. Security doesn't seem to sell? Wider use of encryption would help everyone by reducing misuse and vandalism and increasing privacy. At the moment, the Internet is a large-scale example of the benefits of encryption. All communications should have an easy-to-use encryption feature that you can turn on or off or set to different levels. Even weak encryption schemes if widespread would make casual vandalism more difficult.

Text verses Voice & "Data": Text is the most efficient form of communication because it is compact. If you compare the size of an email message (text message) to a 3-minute audio file, the audio file is much larger. Voice requires more bandwidth, and so do pictures. Generally, text is sufficient for conveying information. However, voice is preferable to most people for real-time conversation. Sometimes large data files, like pictures, need to be transmitted. If text is all that is required, a very efficient system can be designed since a typical email message can be sent by radio in a fraction of a second. Many satcom systems are setup for email, which allows more users per satellite and eliminates the need for continuous real-time coverage. (The email is sent when a satellite comes into view.)

Example of a New System: (see article below)

Survival radio equipment signals over horizon

LOS ANGELES AIR FORCE BASE, Calif. — Military technology has come a step closer to taking the 'search' out of search and rescue. The Space and Missile Systems Center at Los Angeles AFB and a Boeing Company integrated product team recently tested a new military search and rescue communication handheld survival system called Combat Survivor Evader Locator, or CSEL.

The new-and-improved communication survival system successfully withstood two weeks of rigorous testing. Recent tests were performed at Hurlburt Field, Fla. "Preliminary results show that overall testing was successful," said Lt. Col. Norm Albert, CSEL program manager for the Global Positioning System Joint Program Office at SMC. This is the first military search and rescue system that provides multi-satellite, over-the-horizon communications and uses the latest-generation military global positioning system module in a small, rugged, lightweight handheld survival system. It's scheduled for production in 2002.

During the testing, search and rescue operators successfully tested CSEL in different scenarios and environments. One scenario simulated a wounded aircrew member trying to bring search and rescue forces to his position.

Through its use of global positioning and encryption systems, program office officials say the radio will dramatically improve the probabilities of a safe rescue and thereby save lives. The over-the-horizon relay segment provides two-way secure messaging and location via existing satellite systems.

— Ms. Ronea Alger, SMC Public Affairs

Future DOD software configurable multiband radio called JTRS:

JTRS Benefits

JTRS is designed to replace many unique legacy systems with a family of common radios. JTRS will deliver numerous benefits, including:

- Modularity that will enhance force flexibility and technology upgrades
- Greater bandwidth and throughput, to provide greater information to the end user at a faster pace
- Faster transmission speed - in excess of 5 megabits per second
- Reduced weight and footprint, to deliver greater capability in ever smaller packages
- Commonality with commercial standards, enabling DoD to leverage commercial/military communications resources and infrastructure
- Ease of technology insertion and sustainment
- Supports low-probability of intercept and antijam capabilities
- Flexibility to improve spectrum allocation - radio network managers will be able to select and move certain waveforms into different frequency ranges
- High reliability
- Accelerated procurement and fielding

- Interoperability with legacy DoD systems, allies' systems, and across JTR sets
- Cost-efficiency: waveform applications will be developed only once (and ported on multiple hardware configurations and distributed to all Services), as opposed to multiple efforts to produce legacy systems
- Ease of Adaptation: JTRS users can add functionality and adopt multiple waveforms quickly and easily through software downloads. JTRS radios will support multiple security keys.
- Ease of Maintenance: In many cases, a single JTRS radio with multiple waveforms can replace many separate tactical radios. Because JTRS radios are software reprogrammable, they will also offer a longer functional life (reduced obsolescence)
- Dynamic, wireless networks through self-organizing, self-healing ad hoc networking

Capabilities

JTRS will ultimately enable a powerful array of increased communications capabilities. Currently planned to span a frequency range of 2 megahertz to 2 gigahertz, JTRS has the potential to increase the top end frequency to 55 GHz to satisfy space communications requirements.

JTRS will provide simultaneous, real-time access to multiple channels of information. A warfighter will be able to access maps and other visual data, communicate with a command post, coordinate with allies, and obtain information directly from sensors in a network centric warfare environment. JTRS will provide:

- Protocol conversion to bridge between communications systems using dissimilar protocols
- Ability to retransmit/cross-band information between frequency bands/waveforms supported -- allowing JTRS to connect with non-interoperable legacy networks
- Ability to operate on multiple full- and/or half-duplex channels simultaneously
- Scaleable networking services for connected radio frequency (RF) networks, host networks and hybrid networks

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VHF/UHF/Microwave Radio Propagation: A Primer for Digital Experimenters

Barry McLarnon

Conclusions

Radio propagation is a vast topic, and we’ve only scratched the surface here. We haven’t considered, for example, the interesting area of data transmission involving mobile stations - maybe next year! Hopefully, this paper has provided some insight into the problems and solutions associated with setting up digital links in the VHF to microwave spectrum. To sum up, here are a few guidelines and principles:

- Always strive for LOS conditions. Even with LOS, you must pay attention to details regarding variability of refractivity, Fresnel zone clearance and avoiding reflections from the ground and other surfaces. Non-LOS paths will often lead to disappointment unless they are very short, especially with the high-speed unlicensed WLAN devices. Their low ERP limits and high receive signal power requirements (due to large noise bandwidths, high noise figures and sometimes, significant modem implementation losses) leave little margin for higher-than-LOS path losses. Hams are not encumbered by the low ERP limits, but it can be very expensive to overcome excessive path losses with higher transmitter powers.

- Use as much antenna gain as is practical. It is always worthwhile to try both polarizations, but horizontal polarization will often be superior to vertical. It will generally provide less multipath in urban areas, and may provide lower path loss in some non-LOS situations (e.g., attenuation from trees at VHF and lower UHF). Also, interfering signals from pagers and the like tend to be vertically polarized, so using the opposite polarization can often provide some protection from them.

- There are advantages to going higher in frequency, into the microwave bands, due to the higher antenna gains which can be achieved. The tighter focusing of energy which can be achieved may result in lower overall path loss on LOS paths (providing that you can keep the feedline losses under control), and less multipath. Higher frequencies also have smaller Fresnel zones, and thus require less clearance over obstacles to avoid diffraction losses. And, of course, the higher bands have more bandwidth available for high-speed data, and less probability of interference. However, the advantage may be lost in non-LOS situations, since diffraction losses, and attenuation from natural objects such as trees, increase with frequency.

Radio propagation is seldom 100% predictable, and one should never hesitate to experiment. It’s very useful, though, to be equipped with enough knowledge to know what techniques to try, and when there is little probability of success. This paper was intended to help fill some gaps in that knowledge. Good luck with *your* radio links!
