Communications

(Vanguard Optional Rules)

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Radio communications

The information society demands instant access to information in any part of the world at any time of the day. Communication technology, both wired and wireless is an important part of the infrastructure. Wireless communications mostly takes place in the radio part of the electromagnetic spectrum. Although colossal advances have been made since the late 20th century in terms of electronics and later optical systems, the propagation of radiowaves, the operating principles of antennas and the random noise from the surrounding environment are all governed by physics, which may be circumvented in some cases using clever engineering, but mostly it's these factors that limit the range and data throughput of communications systems.

Radio waves are characterized by either frequency or wavelength. The two are directly related, the wavelenght is inversely proportional to the frequency. This means that when we increase the frequency, the wavelength gets shorter. The radio spectrum is split into several bands:

- Low Frequency (LF): 30-300 kHz or 1-10 km wavelength
- Medium Frequency (MF): 300-3000 kHz or 100-1000 m wavelength
- High Frequency (HF): 3-30 MHz or 10-100 m wavelength
- Very High Frequency (VHF): 30-300 MHz or 1-10 m wavelength
- Ultra High Frequency (UHF): 300-3000 MHz or 0.1-1 m wavelength
- Microwaves (MW): 3-30 GHz or 1-10 cm wavelength
- Millimeter waves (MMW): 30-300 GHz or 1-10 mm wavelength

The lowest bands (LF - HF) are usually used for broadcasting at high power. At these frequencies, the waves propagate along the ground and by bouncing off the ionosphere meaning waves at these frequencies can reach beyond the horizon. These bands are mostly used for voice and very slow data connections, and radio beacons.

Starting at the VHF bands, it becomes easier to shape the radio waves into beams (as opposed to waves going out in all directions), the available bandwidth is higher but the waves only reach as far as the horizon [1]. This is because the waves penetrate the ionosphere and are not reflected back down again. Surrounding terrain, such as forests, hills and buildings begins affecting the waves, but in different ways. Microwaves are dispersed by heavy rain, and millimeter waves by both rain and fog. VHF and UHF are mostly used by mobile communicators such as cellphones and radios, Microwaves are used by LEO comsats and sattelite-phones and low-capacity line-of-sight radio links. Millimeter waves are used for direct LOS links between two points on ground, in orbit or in space.

[1] The radio waves do bend a bit in the athmosphere, so the horizon for radio waves lies beyond the visual horizon.

Rules:

Every transmitter has a base range, which is the communication range to a normal receiver with a omnidirectional antenna. For receivers with more directional antennas[2], the range is multiplied by the receiver's *reception factor* (RF) to get the total usable range.

$$\text{Total Range} = \text{Base Range} \times \text{RF}$$

Terrain

For broadcast signals (not microwave links or satellite transmitters), terrain affects signals at VHF frequencies and upwards. To find the total range, determine the type of terrain and adjust accordingly:

Terrain Type	Range
Open ground/Hilly/Suburban:	100 %
Urban/Mountains:	25 %
Indoors/Forest	15 %

Ground-to-Orbit

For signal transmission from ground to orbit, or from orbit to ground, reduce the range to 33% of the base range (to account for losses in the ionosphere). This rule only applies for worlds with an athmosphere.

Weather

For microwave communicators in heavy rain, the range is reduced to 33% of the base range. For millimeter wave communicators in heavy rain, the range is reduced to 10% of the base range. For millimeter wave communicators in fog, the range is reduced to 33%. Weather factors and terrain influence on range are cumulative.

Line-of-sight and beyond-the-horizon communications

Broadcast radios, such as cell-phones and backpack radios do not need direct LOS to communicate. Data links and satellite links must have completely unobstructed LOS to communicate. All communications at VHF and above is limited by the radio horizon (see Appendix)

Satellite signals and High-capacity LOS data links are not subject7 to terrain influence, but they are subject to weather factors.

[2]Directional antennas are antennas that are more sensitive to waves coming from one direction than omnidirectional antennas, e.g. TV antennas or satellite dish antennas.

Example:

Quist has a portable comm station (base range 400km). He tries to contact a small satellite with an RF of 100, at a range of 15,000 km. The maximum range of communications is then 40,000 km (Range$\times$RF), but as Quist is sending from within the athmosphere, the range is divided by 3, for a total of 13,300 km. Quist's signal has lost too much strength before it reaches the satellite. As the satellites transmitter has a more powerful transmitter, the base range for the satellite is higher, or 2000 km. Quist's comm station has a reception factor of 180, so the maximum range of communication is 120.000 km, including ionospheric attenuation. Quist can receive signals from the satellite, but he cannot send signals to it. If it were to start raining, Quist would lose the connection (he is using a millimeter wave sat-link), as the range would be divided by 10 to a grand total of 12,000 km.

> **Two communicators may only communicate provided they use the same frequency band, i.e. a VHF comm-station cannot talk to a UHF handset which cannot talk to a MW SatLink, but a HF Military radio could communicate with a HF civilian comm-station provided, of course, the two were in range.**

Mobile Communicators

A typical mobile communicator normally includes a microphone and speakers or a headset, a data display (varying from a small alphanumeric display to a high-quality electro-optical matrix), and a short-range microwave or infrared link (to connect to other devices, e.g. computers). Voice recognition technology has rendered the numeric keypad all but obsolete in cellphones and radios. For digital radios used by emergency services and on frontier worlds, a digital keypad is often included should the voice recognition software fail, or to spell out short text messages in case the microphone should malfunction. Personal communicators include hand-held/worn devices as well as small vehicular communicators.

Digital Radio: Digital Radios are very similar to the analog radios of the 20th century apart that they use digital modulation techniques to utilize the bandwidth even more effectively. Digital radios commonly allow for direct communications between two radios, communications via a base station or repeater. Hand-helds or vehicular radios in-between two radios communicating can be used as repeaters, the signal leap-frogging across to the desired destination. Digital Radio systems allow for one-on-one calls as well as groups of people.

Cellular Phones: This is the ubiquitous mobile phone that has been around since the late 20th century. The 22nd century has smaller phones, more functionality and faster connections but they operate on similar principles. Cellular phones do not send signals to each other, but to a nearby base station. The base station then routs the call to where ever the user would like, even if it's a mobile phone in the same cell. Two cell-phones do not speak directly to each other. The range of a cell-phone is usually unimportant in large cities, as the cellular network is usually dense enough to cover the whole city area. In less populated areas, the cell-phone can quickly lose contact to the cellnet.

Personal Data Communicators: This is a special form of communicator, as it is not intended to transmit data from the wearer (e.g. voice or typed input), but data from sensors attached to the wearer such as biomedical sensors, video feed, radiation readings, etc. PDCs are often used as emergency beacons. PDCs have no microphone or speaker, and often only a small alphanumeric display to display the frequency/status of the device. On the other hand, there are numerous optical fiber jacks for sensor input. Larger versions are used on vehicles, specially remote-controlled drones. These are called Vehicular Data Communicators, or VDCs.

Satellite Phones: A satellite phone is similar to a regular cell-phone, but consumes more power. A small antenna directs the signal upwards, but not in a tight beam. Satellite phones normally transmit/receive in the lower end of the microwave band, 6 GHz (C-band) or 12 GHz (Ka-band).

Comm Stations

Comm stations are larger and more powerful than mobile phones, digital radio handsets and small vehicular communicators. Comm stations are used for long-range terrestrial communications as well as satellite communications. A comm station consists of a transceiver, one or more antennas, and a minimum of one set of earphones/microphones, display and keyboard, in addition to several optical fiber input/outputs. Large comm-stations can have many operators at the same time.

Comm stations come in all sizes and flavours, from portable to fixed installations. Advanced comm-stations have more than one type of transmitter, but they have to be connected to the proper antenna to function properly. Comm-stations can much more flexible than ordinary communicators, being able to adapt to different types of systems in a very short time, including cellular phone networks and digital radio nets.

> **Cell phones, digital radios and comm-stations can all speak with each other, provided they are in communications range and use the same frequency band.**

Data Links

Data links are similar to comm stations, but are used to connect computers/devices rather than people. They are used instead of optical fibres in hard-to-reach places where the need for data is lower and the price of fiber would be prohibitive. Data links are normally microwave or millimeter wave transmitters connected to a large antenna that shapes the waves into a tight beam. By aiming the antennas at each other (taking atmospheric bending and/or refraction into account), the links can send data across at very high speeds, albeit not at fiberoptic speeds. Line-of-sigh links need a clear line of sight and elevated antennas to avoid ground reflections from interfering. For links between two remote locations, repeating stations are needed in-between. Microwave/Millimeter wave links are often placed on high-buildings or on large hills/mountains. The range given for the point-to-point data links is the free-space range. For ground-based links, the radio horizon must be taken into account.

Communication Satellites

Satellites are used for a number of purposes. Civilian communications satellites are used to broadcast information to a large area, or to relay signals from one ground station to another. Chains of low orbit satellites can cover the entire globe, enabling access for small hand-held satellite phones without consuming a lot of power. Military satellites provide a secure link between soldiers in the field and HQ, pick up enemy radio transmissions and many more. Satellite orbits are divided in three groups, Low Earth Orbit, Medium Earth Orbit and Geosynchronous Earth Orbit, or LEO, MEO and GEO.

Satellite antennas have multiple beams, each one as small as a few tens of kilometers wide. The total coverage area for a satellite is called it's *footprint*. The power and data rates for a satellite are given as (Power per beam) and (Data rate per user). There is a certain maximum of users that can use a single beam at a time (users in two separate beams do not influence each other).

LEO Comsat: Small satellite with a 4×4 m flatpack antenna array, divided into smaller spotbeams. LEO satellites orbit the earth at an altitude of 200-2,000 km.

GEO Comsat: Large satellite with a 20m dish antenna and high-power transmitter. The altitude of GEO satellites orbiting earth is around 36,000 km.

SIGINT Satellite: SIGINT, or signals intelligence, is the interception and subsequent analysis of enemy radio traffic. SIGINT satellites have very large antennas and state-of-the-art military electronics, making interception of land-based radio traffic possible. SIGINT satellites normally orbit somewhere between LEO and GEO.

Rule: SIGINT Satellite

When determining if SIGINT Satellites pick up a certain piece of ground-traffic, take the range of the communicator, adjust for terrain and multiply it by the SIGINT satellite's Reception Factor. If the resulting range is greater than the range to the satellite, the satellite picks up the signal. This means that mobile phones are easier to intercept than LOS links, as directive antennas don't radiate much outside their main beam.

Military Communicators

Military communicators are essentially not so different from civilian versions. The main differences are the level of encryption, and the multiple tiers involved in the military communications hierarchy.

Starting at the bottom of the communications hierarcy is the common soldier. Every grunt in the unit is issued a helmet with an integral short-range UHF radio capable of transmitting/receiving voice and limited amounts of data. The helmet communicator also functions as a Personal Data Transmitter, relaying position, vital signs, ammunition reserves, etc. to the commander on a burst basis, meaning that this information is collected periodically and sent in short bursts to the platoon commander. If the need arises, video signals from the helmets camera can be sent, but this requires continuous transmission which could give the unit's position away.

The squad leader also has a helmet communicator identical to the common grunts. The platoon commander, on the other hand, has a UHF communicator, that in addition to having more bandwidth than the standard-issue communicator is combined with a folding touch-screen display mounted on the forearm. The data received from the troops is analyzed by the computer's C^3I software, and friendlies and hostiles can be placed on the commander's map using advanced Geographic Information Systems (GIS).

Every platoon's link to the outside world is the radio man. A standard-issue backpack radio includes multiple transceivers: Auto-tracking Ka-band satellite link, UHF radio for platoon communications, a long range HF backup and a PDT data receiver. In addition, there is a millimeter wave transceiver that can be hooked up to an external antenna for tight-beam communications. A standard-issue folding dish antenna may be carried in several parts by members of the platoon.

Normally, each squad is assigned its own channel to use for squad level communications. Squad leaders and the platoon commander have a separate command channel. Although normally the commander only uses the command channel, he can monitor each squad channel should he so choose. The backpack radio functions as a control center for the remote units, and the commander can split or join squad channel as he sees fits through his own communicator/forearm display.

All military communicators have dedicated encryption processors delivering standard encryption to voice and data signals. The backpack radio includes a 250 CPP computer sometimes used to heavily encrypt short but important messages to be sent by satellite link, or especially HF-radio.

Data for typical communications gear is listed in Tables 2 – 5

Communicator	Frq.	Power	Range	RF	Data Rate
Cellphone	UHF	260 mW	10 km	1	0.2 du/s
Adv. Digital Radio	UHF	5 W	32 km	1	0.2 du/s
Portable comm-station	UHF	270 W	160 km	1	0.2 du/s
Vehicular comm-station	UHF	2 kW	320 km	1	0.25 du/s
Fixed comm-station	UHF	4 kW	320 km	1	0.5 du/s

Table 1: Civilian communicators.

Communicator	Frq.	Power	Range	RF	Data Rate
Satphone	MW(C)	1 W	300 km	7	0.1 du/s
Portable Satlink	MMW	35 W	7,500 km	280	0.7 du/s
Vehicular Satlink	MMW	100 W	25,000 km	730	1.25 du/s
Fixed Satlink	MMW	150 W	50,000 km	4000	2.5 du/s

Table 2: Satellite communicators.

Type	Frq.	B/U	P/B	Range	RF	Data/U	Diam.
LEO ComSat	MW(C)	20/5	2.5 W	250 km	185	0.1 du/s	130 km
LEO MilSat	MW(Ka)	40/10	10 W	500 km	390	0.2 du/s	60 km
GEO ComSat	MMW	20/30	100 W	1000 km	1,400	2.5 du/s	2,000 km

Table 3: Comm Satellites. B/U denotes (number of beams/number of users per beam). P/B denotes transmission power per beam. Beam Diam. denotes beam diameter. Data/U denotes the available data rate per user.

Type	Frq.	Power	Range	RF	Data Rate
Sm. MW Link	MW	0.5 W	60 km	25	10 du/s
Lg. MW Link	MW	2 W	150 km	140	25 du/s
Sm MMW Link	MMW	0.2 W	20 km	60	20 du/s
Lg. MMW Link	MMW	5 W	150 km	350	50 du/s

Table 4: High-capacity Data Links

Type	Mode	Frq.	Power	Range	RF	Data Rate
Helmet Comm	Broadcast	UHF	0.5 W	15 km	1	0.05 du/s
PDT	Broadcast	UHF	0.35 W	7.5 km	1	0.2 du/s
Backpack Radio(*)	Broadcast	UHF	4 W	15 km	1	0.4 du/s
	Broadcast	HF	50 W	1,000 km	1	0.05 du/s
	SatLink	MW(Ka)	2 W	500 km	25	0.2 du/s
Comm. Vehicle	1×Broadcast	HF	200 W	1,750 km	1	0.05 du/s
	5×Broadcast	UHF	1 kW	140 km	1	0.4 du/s
	5×SatLink	MW(Ka)	2 W	500 km	140	5 du/s
Brigade HQ	3× Broadcast	HF	1.5 kW	4,000 km	1	0.05 du/s
	10× Broadcast	UHF	2.5 kW	200 km	1	0.4 du/s
	10× SatLink	MW(Ka)	2 W	500 km	220	12 du/s

Table 5: Military Comm Stations. (*) The backpack radio includes a PDT receiver that can receive and relay PDT data for up to 40 units. All Satlinks in this table are Military LEO Satlinks. Standard encryption assumed on all communications.

The Radio Horizon

As mentioned earlier, signals at VHF and above do not travel further than the radio horizon. Normally, the range to the visual horizon is found by the formula:

$$d_v = \sqrt{2R_p h}$$

where d_v is the range to the horizon in meters, R_p is the planet's radius (in meters) and h is the communicator's elevation (also in meters). Even at higher frequencies, radio waves do follow the planet's curvature slightly. Normally, the radio horizon is found by calculating with 4/3rds of the planetary radius:

$$d_r = \sqrt{\frac{8}{3}R_p h}$$

where d_r is the radio horizon, in meters.

For those of you that aren't mathematically inclined, I've taken the liberty of calculating the radio horizon on Earth for a few select values of elevation:

Please note, that this is from one communicator to a point at sea level. In order to find the maximum line-of-sight range between two communicators, their respective horizon ranges are added together.

	VHF	UHF	MW	MMW
Reception Factor (RF)	75	300	1,000	12,000

Table 6: SIGINT Satellite Reception Factor for Frequency bands.

Type	Frq.	Power	Range	RF	Data Rate
Gnat	VHF	1 μW	150 m	1	0.02 du/s
Fly	VHF	5 μW	300 m	1	0.02 du/s
Bird	VHF	2 mW	2.5 km	1	0.02 du/s

Table 7: Espionage Gear

Example

Quist and Lund want to communicate with their brand-new ultra-power microwave transmitters, each having a maximum range of 10.000 km. Lund is standing on the beach while Quist is standing on the crow's nest of the supertanker "OilHog", at an altitude of 100 m. The radio horizon range of Lund is 6 km, while Quist has a radio horizon range of 41 km. The maximum LOS range between them is 47 km. It's a bit unfortunate that the supertanker is 800 km from shore. They shouldn't have listened to that radio salesman! Luckily enough, Quist and Lund's colleague, Bergmann the pilot manages to relay the signal from his plane directly inbetween the two, at an altitude of 10,000 m. Both agents have a LOS to Bergmann, but not each other.

Elevation	Radio Horizon
2 m	6 km
5 m	9 km
10 m	13 km
20 m	18 km
50 m	29 km
100 m	41 km
200 m	58 km
500 m	92 km
1,000 m	130 km
2,000 m	180 km
5,000 m	290 km
10,000 m	400 km

Table 8: Radio Horizon range (for one communicator) given by elevation.