THE AMERICAN MUSEUM OF NATURAL HISTORY
CENTRAL PARK WEST AT 79TH STREET
NEW YORK 24, N. Y.

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RELEASED FOR 12 noon, Monday, October 13, 1952

RADIO COMMUNICATION ACROSS SPACE-- *
SHIP-TO-SHIP AND SHIP-TO-PLANET

by

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At first glance, radio communication across space looks like a major project. The moon is two hundred and thirty-eight thousand miles away. This appears to be an unsurmountable barrier if it is compared to the service area of a fifty-thousand watt broadcast station. However, space radio should not be compared to any terrestrial experience for the obvious reason that planetary conditions do not obtain in space.

For instance, the theoretical distance across which radio signals can be sent seldom meets the actual conditions. This is due to the fact that our atmosphere is not an entirely transparent medium for the passage of electromagnetic waves. Transmission distances are affected by the frequency of the radio signals, the topography, the electrical condition of the soil, the time of the day and the season of the year, climate and meteorological conditions and, last but not least, the era of the sun-spot cycle.

If the earth were an airless planet, the distance across which a transmission could be made would be the geographical horizon for all frequencies, because electromagnetic waves tend to propagate in straight lines unless acted upon by some outside force.

But the solar output causes layers of ionization in the upper, rarified portion of our atmosphere, and these several layers cause reflection or absorption of radio waves that impinge upon them.

The other conditions mentioned are variable, so that the following statements are generalities instead of being firm and inviolate:

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* Text of speech delivered at the Second Symposium on Space Travel at the Hayden Planetarium, American Museum of Natural History, October 13, 1952.

Frequencies below the top of the broadcast band are influenced by the electrical condition of the soil and the activity of the lower ionosphere, called the 'D Layer.' Transmission beyond the horizon is fairly constant and reliable.

Frequencies above the top of the broadcast band are less affected by ground conditions. These frequencies pass through the lower ionosphere but are caught by the upper layers E, F-1 and F-2. Transmission beyond the horizon is spotty and sometimes a bit fantastic. A transmitter in New York may be heard with clarity in Los Angeles while a receiver in Philadelphia cannot get a trace of the signal. Other conditions may produce readable signals also in Chicago and Denver as well as Los Angeles while points between these cities are totally blank.

As the planet rotates, bringing new areas under the direct rays of the sun, the layers shift in altitude and activity. This can produce a situation whereby a radio contact may be held between two widely separated places like Chicago and New Zealand for a two-hour period while the layers are shifting above the transmission path half way between the two places. The signal will come in strong and clear for about two hours and then will fade out completely until the same time next morning.

These skip-layers have been mapped and charted so that if we pick our frequency, and the time of the day, and season of the year, we can predict with a fair degree of accuracy whether we can make contact with a certain place.

But as we inspect the radio spectrum above fifty megacycles, which is somewhat lower than Television Channel Two, we discover that the atmosphere is becoming more and more transparent. Except under freak conditions, frequencies above fifty megacycles pass through the ionosphere and into space. This is why the general service area of a television transmitter tends to be that of the geographical horizon. Stations below fifty megacycles are reflected back from the ionosphere to some point beyond the horizon.

In a sense, this difficulty with terrestrial radio communications is similar to the problems of space travel. All the problems seem to lie below the first five hundred miles of altitude.

Once in space, radio travels in straight lines through an absolutely transparent medium. There are no natural barriers in space; there is nothing to cause reflections or refractions any of which can cause the received signal to vary greatly from the simple formulas for radiated power.

Out in space we can express our communications system in a mathematical equation and expect it to hold firm. Radio signal strength, like light, diminishes proportionally to the inverse square of the distance. We can compute, therefore, just how much signal we will have left at the end of a given distance. Or conversely, we can compute how much signal we will have to start out with if we require a given amount for good reception across that distance.

This formula will be shown on a slide:

$$Pt = \frac{\beta_1\beta_2}{40} \times \frac{BL^2}{r^2 r^4} \times \left(\frac{F}{K}\right) \sigma \left(\frac{S}{N}\right)^*$$

* (NOTE: In subsequent appearances of this equation, please substitute $\beta_1\beta_2$ [Beta One, Beta Two] for B_1B_2.)

The unknown, Pt, on the left, is the power of the transmitter as stated in watts. The rest of the terms on the right will be explained as we go along. At each step we will replace the term with the appropriate numerical statement until we can sum this up by plain arithmetic and get our unknown transmitter power.

Perhaps the best place to start is at the end. The S over N stands for the Signal-to-Noise ratio. This will be about the same for any communications system we care to design, so let's take care of it first.

Noise is the bugaboo of communications. Interference from other stations and just plain random noise are two of the important factors that limit the useful range of any radio equipment. Noise comes of two basic causes, natural and man-made.

Natural noise is created mostly by lightning and coronal discharges in storms and bad weather conditions, either locally or at some distance.

Man-made noise comes from the fact that men learned more about electricity than they have about radio, much sooner. Electrical machinery, diathermy equipment, X-ray devices, electric razors, automobile ignition systems, doorbells, and anything else that the human race has learned to do by electricity, all succeed in creating noise.

Noise in space is all natural. There is galaxy noise, first discovered by 1 Dr. Jansky in 1933, and since then expanded into the study of radio astronomy. There seem to be a lot of dark stars that radiate radio waves of one frequency or another. This noise is not of a high level and the spectrum is spotty and discontinuous so that a convenient hole can be used for space radio. The second type 2 of cosmic noise is thermal noise. Solar activity throughout the galaxy produces energy that radiates along a continuous spectrum. This radiation is of equal amplitude across wide bands and its time-amplitude curve is non-recurrent. In other words, it is just plain noise, differing from galaxy noise in that the latter does have definite radiation frequencies. The third type of cosmic noise is 3

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anomalous solar radiation which comes from Sol and tends to rise and fall with the sun-spot cycle.

Now, the signal-to-noise ratio must always be greater than unity. In fact, a one-to-one signal-to-noise ratio is a completely hopeless signal to read. A ten-to-one ratio provides better intelligibility, but even here the random noise peaks can frequently coincide with some difficult sound of the voice and cut a hole in the flow of intelligence.

Signal-to-noise ratio also depends upon the individual listening, the person talking, and the importance of the message. A fine symphony can be ruined by a noise factor that might be considered only a petty annoyance to a man whose life depended upon listening carefully.

The voice of the speaker has a lot to do with deciding upon an acceptable signal-to-noise level. Some voices seem to cut through a noise level when others are blanketed. This has to do with enunciation, voice pitch, and the rapidity with which the words are articulated.

The hearing ability of the listener is another important factor. Some people are extremely sensitive to bursts of noise which tend to cut into their concentration level and cause them to miss some of a message. Other people can listen to a conversation through a rather heavy noise level and not miss a syllable.

These are the reasons why the signal-to-noise factor is expressed as a fraction and not a generally accepted constant.

However we know that our expeditionary party on the moon is important. Let's take a mixture of one part noise to one hundred parts signal and enter the figures in our equation. This equation now becomes:

$$(1) \qquad Pt = \frac{B_1B_2}{40} \times \frac{BL^2}{f^2r^4} \times \left(\frac{F}{K}\right) \sigma \left(\frac{S}{N}\right)$$

$$(2) \qquad Pt = \frac{B_1B_2}{40} \times \frac{BL^2}{f^2r^4} \times \left(\frac{F}{K}\right) \sigma \frac{100}{1}$$

The next term in the equation is the Greek small letter Sigma, and represents a sort of safety factor. It stands for the probability of signal fading. 5 The atmospheric conditions we experience here on earth cause alternate reinforcement or cancellation of radio waves, depending upon varying conditions of the ionosphere. Shifting of the ionized layers as the earth rotates to bring a new area into the sunlight region is known to create conditions where a signal may take two paths in its course from transmitter to receiver. One course may reinforce the signal, while another may cause cancellation of the signal. The result is fading,

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and anyone who has ever listened to the short-wave bands will understand how this strengthening and weakening of the signal can affect communications.

We do not expect to find any such conditions in space, but there may be conditions of the upper atmosphere that will affect the signal strength as we aim our radio at the moon.

The signal-to-noise ratio mentioned previously is based upon the minimum requirements; if for any reason the signal is attenuated along the way, this loss must be made up at the transmitter. We do not care how strong the signal is so long as it never falls below the receivable level.

I believe that a fading factor of ten should be adequate to cover any contingency. In this I confess a lack of experience and data. Until someone succeeds in establishing a radio receiving station in space, at which the signal strengths can be measured with accuracy, no one can do more than hazard a guess. But a figure of ten-to-one in signal strength variation due to upper atmospheric conditions is a rather pessimistic opinion.

So we will replace the letter Sigma with the numerical ten, to stand for a ten-to-one safety factor against fading.

Our equation at present reads:

$$(2) \qquad Pt = \frac{B_1 B_2}{40} \times \frac{BL^2}{f^2 r^4} \times \left(\frac{F}{K}\right) \sigma \left(\frac{100}{1}\right)$$

$$(3) \qquad Pt = \frac{B_1 B_2}{40} \times \frac{BL^2}{f^2 r^4} \times \left(\frac{F}{K}\right) 10 \left(\frac{100}{1}\right)$$

The foregoing terms are likely to remain about the same no matter what form of radio communication we use. This is why we disposed of them first. But now is the time to discuss the spectrum which will be used in space radio.

I have mentioned that the atmosphere becomes reasonably transparent to the microwave bands. The microwave frequencies lie between approximately one thousand and thirty thousand megacycles. They are called microwaves because their wavelength is extremely short. So short, in fact, that it is far easier to measure the wavelength than it is to measure the radio frequency.

These microwaves are used in the several radar systems. Therefore equipment has already been designed for their efficient use. We have had quite a bit of experience with microwaves so that we can predict their performance with a good degree of accuracy. Microwaves are also excellent carrier waves for our space radio because they are easy to confine in a tight beam using antenna arrays of a

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convenient size. Such reflectors can be handled with ease either on the earth, on the moon, or in space.

The spread, or dispersion, of any beam is a function of the wavelength of the radiation and the area of the antenna array. The wider the reflector, the narrower the beam will be for a given wavelength. This can be given approximately by a fairly simple formula:

The angle of dispersion in degrees is equal to six point seven times the wavelength, divided by the width of the antenna.

The selection of a microwave band can be justified by this formula alone. A six-foot reflector, using three centimeter microwaves will produce a beam about one degree in spread. Since the moon subtends an arc of a half degree, our beam will cover more than the face of the moon if we use three centimeter microwaves and a six-foot parabolic reflector.

The question will arise as to why we permit the beam to splash out across waste space. Why not use a fifty-foot reflector, similar to the radio telescope down at the Naval Research Laboratory? This job is fifty feet in diameter, mounted on gymbals, and is used in the study of radio astronomy. Such a reflector would be extremely efficient, producing a beam of three centimeter waves less than 0.15 degrees in spread. However, I have selected the six-foot parabolic dish because we can produce them in mass and we have. Furthermore, the handling of a six-foot metal dish makes less of a major project. A fifty-foot spinner in space would be quite a job, not for the handling under free-fall conditions, but the job of taking it aboard the spacecraft in segments and then putting the segments back together again once the ship was in space. Also the big dish would have to be disassembled before the landing on the moon, and then might give some trouble during the stay there. It seems to me that the boys would spend more time taking the big dish apart and putting it together again than they would in using it for space communications.

A dish of that size, even made of a perforated type of construction, adds quite a bit of mass to the pay load of the ship. On the other hand, a six-foot disc of aluminum can be carried with ease by one man.

Without a doubt, the big radiators will be built after space travel becomes a regular thing. But for the present and some time to come the smaller parabolic dish will be ample.

I also wish to point out that having a tight beam, one of less than 0.15 degrees, provides the operator with quite a bit of trouble. In receiving, as the

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fifty-foot dish is used exclusively, the operator can turn his antenna to the direction that actually gives him the strongest signal. But in transmitting, all the operator can do is point his antenna and hope that the beam he is pouring out is hitting the right spot. A feedback loop from the receiver could probably be constructed, but this strikes me as complicating a simple program just for the benefit of using a more efficient antenna. I can easily imagine a pair of operators spending most of their time adjusting the antennas instead of using their radio power for getting a message across.

Accepting a six-foot parabolic dish for our antenna array because of convenience, availability and compromise, and using this with three centimeter microwaves provides us with a fair beam spread and also the tolerance necessary to point the beam and be certain that the spread is covering the target.

We might consider Mars for a moment. It seems logical to ask, "Why spray the solar system with a one-degree beam when Mars is only a tiny spot?" I wish to point out that any real tight beam aimed at Mars must not be aimed at Mars. We see Mars where it was a few minutes previously. Our tight beam must be aimed where Mars will be when the beam arrives. It seems better to take the spread and be certain of our results.

Three centimeter microwaves have been selected because of the availability of equipment. Waveguide for three centimeter microwaves has been built for the past several years. The duplexing assembly which permits the use of the same antenna for transmitting and receiving can be bought from several sources. Microwave receivers as well as transmitters exist. We need only buy a surplus 'X-Band' Radar equipment and convert it to communications use and our system is set up and ready to go to work.

We might gain an advantage by going to a shorter wavelength, but we find that we are stepping close to the danger point. Water vapor has a resonance absorption band at 1.3 centimeters, and oxygen has resonance bands at 0.5 and 0.25 centimeters. These absorption bands are characteristic of the atomic spectrum, which in the region of visible light produce the Fraunhofer Lines.

Let's remain with three centimeters. It is a convenient figure and I like it.

Now, three centimeters corresponds to a frequency of ten thousand megacycles The small letter f in the formula represents the frequency, which must be squared. This comes out to ten to the eighth power.

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And the small letter r stands for the radius of the parabolic reflector in feet. It is raised to the fourth power because we have two similar reflectors, one at either end. The gain in power is roughly proportional to the square of the area of the reflector dish whether the antenna is to be used for transmission or reception. If we were to use dishes of different sizes, the radius of each must appear, squared, as: Rt^2 times Rr^2, but since we are using the same sized dish, we can lump these two factors into one and call it R to the fourth power. The radius of our reflectors is three feet. Three to the fourth power is eighty-one.

We now add the above figure to our equation:

$$(3) \qquad Pt = \frac{B_1B_2}{40} \times \frac{BI^2}{f^2r^4} \times \left(\frac{F}{K}\right) \times 10 \times \left(\frac{100}{1}\right)$$

$$(4) \qquad Pt = \frac{B_1B_2}{40} \times \frac{BL^2}{81 \times 10^8} \times \left(\frac{F}{K}\right) \times 10 \times \left(\frac{100}{1}\right)$$

Having decided upon a frequency, it is now proper to discuss another source of noise, and what we can do about it. This is the noise generated in the receiving equipment itself.

The flow of electrons along a wire, through a resistor, or their emission from a tube cathode is never smooth and even. The energies in this electron flow follow Maxwell's Law of Random Distribution of densities and energies and motions. I have heard a rather quiet, sincere professor state that the flow of electrons is as smooth as dumping a load of soft coal into an empty cellar.

Electrons vibrate all the time. They vibrate faster when heat energy is introduced. The cathode must be hot before the electrons will emit. Current passing through a resistor produces heat. Therefore there is always a low level racket going on right in the receiver itself.

This is known as thermal noise and if you will pardon the heartfelt expression, it is a darned nuisance.

Thermal noise can be computed with accuracy. The figures include Boltzmann's constant, the temperature of the device under consideration, and the bandwidth of the listening amplifier. The resulting figure is a noise output stated in watts. This thermal noise level is the theoretical limit of the sensitivity for any amplifying equipment.

Radio equipment for a good many years has been sensitive almost down to the theoretical limit. In the broadcast band we can design a receiver with a noise figure of merit not more than two or three. In the short-wave bands our equipment loses its efficiency and the figure begins to creep up. In the microwave region,

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the inherent noise in the sensitive elements of the receiver rises to a rather distressing figure. Some equipments have been designed with noise figures as low as 40, but the general run of the mill tends to be higher than this.

I'll accept the noise figure of merit for a fair microwave receiver as being 100.

This figure of merit goes in the place of the capital F.

$$(4) \qquad Pt = \frac{B_1B_2}{40} \times \frac{BL^2}{81\times10^8} \times \left(\frac{F}{K}\right) \times 10 \times \left(\frac{100}{1}\right)$$

$$(5) \qquad Pt = \frac{B_1B_2}{40} \times \frac{BL^2}{81\times10^8} \times \left(\frac{100}{K}\right) \times 10 \times \left(\frac{100}{1}\right)$$

Now, one way to lick this noise problem is to lay in a signal of high power. This is why we seldom notice noise levels in our home receivers. But this computation we are making is to derive the minimum required power at our transmitter. Then anything we can produce above this minimum will be gravy.

Another way to lick the noise problem is to use a mode of transmission and reception that is inherently less subject to noise.

Noise is of random nature and invariably amplitude modulated. Therefore the old-fashioned broadcast band with amplitude modulation is about as noisy as we can get. Amplitude modulation has for a noise-improvement factor the figure unity. That would replace the factor K below the line under our receiver figure of merit term F.

For frequency modulation, which everybody knows is less subject to noise than amplitude modulation, we have a noise improvement factor K that can be computed from the system constants.

The noise improvement factor is, for frequency modulation systems, equal to three times the square of the ratio between the carrier frequency deviation and the maximum modulation frequency. Since intelligible speech requires a minimum of five thousand cycles per second, and a carrier deviation of one hundred kilocycles is an efficient figure for F. M. transmission, our figure K becomes 1200.

Entered in the equation, we now have:

$$(5) \qquad Pt = \frac{B_1B_2}{40} \times \frac{BL^2}{81\times10^8} \times \left(\frac{100}{K}\right) \times 10 \times \left(\frac{100}{1}\right)$$

$$(6) \qquad Pt = \frac{B_1B_2}{40} \times \frac{BL^2}{81\times10^8} \times \left(\frac{100}{1200}\right) \times 10 \times \left(\frac{100}{1}\right)$$

$$(7) \qquad Pt = \frac{B_1B_2}{40} \times \frac{.005L^2}{81\times10^8} \times \left(\frac{100}{1200}\right) \times 10 \times \left(\frac{100}{1}\right)$$

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I have also entered the bandwidth figure B as five thousand cycles because we will want to receive everything that is being transmitted, but lose nothing. Therefore the receiver bandwidth must be equal to the transmitter bandwidth.

As we well know, nothing can ever be put together to work perfectly. Therefore are the two factors Beta One and Beta Two. These represent the losses we will experience in connecting our transmitter to the antenna through a wave guide, Beta One; and the return losses caused by connecting our receiving antenna to the receiver input through a similar waveguide, Beta Two. I've been forced to accept a loss of two to one in each case. It sounds deplorable to throw away fifty per cent of our radio frequency power before it even gets out of the antenna, but these are the conditions that prevail. Considering that a locomotive is less than ten per cent efficient and that the gasoline engine is less than twenty-five, we can all be glad that energy and power are cheap and plentiful.

Our equation now becomes:

$$(7) \qquad Pt = \frac{B_1 B_2}{40} \times \frac{.005L^2}{81 \times 10^8} \times \frac{100}{1200} \times 10 \times \frac{100}{1}$$

$$(8) \qquad Pt = \frac{2 \times 2}{40} \times \frac{.005L^2}{81 \times 10^8} \times \frac{100}{1200} \times 10 \times \frac{100}{1}$$

There is one more term. Like all the rest of the terms that work against us, this one lies above the line, and it is the distance between here and the moon, stated in statute miles.

Furthermore this figure is squared.

I have been asked repeatedly whether or not a beamed signal avoids the radiation loss of the inverse square law. I wish it did. It does not. On the face of it, it looks logical to assume that there will be less loss when the signal is crammed into a tight cone than there will be if the signal is permitted to radiate wide open. The unfortunate part of it is that no signal can ever be confined into a perfectly collimated beam. The formula for beam dispersion, if reduced to the final absurdity, shows that for a perfectly collimated beam, the antenna must be infinitely wide.

So no matter how much we dislike to take this loss we must accept it.

The distance from the earth to the moon is two hundred and thirty-eight thousand miles. Squared and inserted in our formula this produces a figure of 56.7 times ten to the ninth power.

Now we can put this set of figures on the calculating machine and the answer can be derived.

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The minimum required power output to provide communication between the earth and the moon is:

$$(8) \qquad Pt = \frac{2 \times 2}{40} \times \frac{.005L^2}{81 \times 10^8} \times \frac{100}{1200} \times 10 \times \frac{100}{1}$$

$$(9) \qquad Pt = \frac{2 \times 2}{40} \times \frac{.005 \times 56.7 \times 10^9}{81 \times 10^8} \times \frac{100}{1200} \times 10 \times \frac{100}{1}$$

$$(10) \qquad Pt = 0.291 \text{ watts}$$

Maybe we'd better move our expedition out to Mars so that I can say something sensational?

Two hundred and ninety-one milliwatts is about the power used in a three-cell flashlight.

At this point I should like to lay a ghost.

Time and again someone has suggested the use of blinker lamps or heliograph for interplanetary communications. I would like to see how far anyone can get with a three-cell flashlight winking the thing at the earth from the Crater Plato. Or conversely, flashing the same at Plato from White Sands.

Yet if the same formula is used for the frequencies for visible light it should come out the same. The trouble is that the factors are different, and most of them deleterious. The skies provide a very high noise level, if you can think of zodiacal light and the lunar brightness in terms of a noise threshold. The bandwidth of the visible spectrum is expressed in a fantastic figure in megacycles. Haze and overcast raises our safety-factor number, and the human eye, when dark-adapted, is troubled by internal lights which are of the same order as thermal noise.

However, three centimeter microwaves can pass through an overcast sky. We have a formula for approximating this, too. It has to do with ten times the rainfall in inches over the past twenty-four hours divided by the square of the wavelength. (This, admittedly, is crude.)

In fact, about the only thing that may change communications as we know it will be time lag. The moon is two point six seconds away for the round trip. This means that two point six seconds must elapse between question and answer. I have prepared a phonograph record that demonstrates the following factors in earth-moon communications:

1. The time lag. Here the recording is made to simulate the earthside station. Our operator can reply as soon as he hears the other end.

2. The noise level of our receiver with no signal between communications.

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3. The quieting as the signal comes in, arriving on an over-all signal-to-noise ratio of approximately one hundred to one. Some noise peaks come in almost to the ten-to-one level.

This recording was cut at home under controlled conditions, the only part of which is not quite fair is the standard practice of using a filter microphone to create the dramatic effect of the use of transmission equipment. Here the band-width is a full five thousand cycles, but the lower register has been cut:

RECORDING

I am not going to play a record simulating a Mars communication. It would take six minutes between statement and rejoinder. The power, incidentally, would be about seven thousand watts to Mars, which might begin to offer us a challenge. On the other hand, the use of one of those fifty-foot antennas I mentioned before would bring the requirements to less than a thousand watts. This would put us back in business again.

But I have been discussing our interplanetary network in terms of voice modulation, as if it were a telephone system. The preference of telephone over telegraphy is, here on earth, a matter of convenience and speed. A man in New York can call a business associate in Los Angeles and place a verbal order, at the same time discussing price, delivery date and probably their golf scores. A telegram will permit similar interchange of intelligence, but it will require longer to complete the whole transaction.

Since I doubt that there will be much interplanetary exchange for purely social purposes where the personal voice-to-voice contact is the most desirable, it seems to me that quite a bit can be done with a radio teletype system.

We can only guess until we get there, of course, but we can make a fairly shrewd guess as to the nature of any interplanetary messages that will take place for some time to come. The only business transacted will be of scientific or military nature. No one is going to set up a transformer plant on Mars, or start making automobile tires on the moon.

It has been suggested that we may find valuable minerals elsewhere in our solar system, but if we accept the opinions of the astronomers and astrophysicists regarding the proportion of the elements throughout the universe, the chances of stumbling upon a lode of uranium ore seem no greater than the chances of finding the same thing here on earth. This rules out the possible mining industry.

Therefore it is my opinion that most of the communications that will take place will be the transfer of technical data, the forwarding of instructions, and ✓

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other information of a totally non-personal nature.

Such information is better transmitted by a teletype system. The result is a roll of paper upon which the facts and figures are recorded for future reference. No operator need write like mad to take down a string of figures as they are spoken and thus take the chance of making a mistake. The teletype machinery offers an excellent cross-check. With the teletype machine it is possible to have a tape punched of the received signal, at the same time that the typing section is recording the message. At the end of such a reception it is possible to retransmit the tape recording back to the point of origin. Any discrepancy between the original transmission and the reply-copy can be investigated and corrected.

Teletype requires less bandwidth than voice modulation by a factor of about twenty-five to one, thus giving us a signal power advantage of that figure. Furthermore, the signals that operate teletype equipment are pulsed modulation, which again offers an advantage in the noise-improvement factor K.

To top this off, pulse modulation offers a valuable increase in power over and above the noise improvement factor. Our work with pulsed magnetron transmitters in radar equipments show that the signalling factor with pulsed power depends upon the peak power delivered and not the average power. The pulsed magnetron delivers a wallop of power during the operating cycle and then rests for a comparatively long period between cycles. For instance, if our pulse length is one microsecond and our pulse repetition rate is one thousand cycles per second, an average power input of one hundred watts results in a pulsed power output peak of one hundred kilowatts.

If we take advantage of all of these considerations, teletype transmission on pulsed modulation can provide good service in space radio all the way across the solar system from here to Pluto, if, as, and when we get that far from home.

So despite the fact that the earth-to-moon link would only have a time lag of 2.6 seconds, I would recommend the teletype system due to the permanence of the record of such transmissions. It is true that voice can be recorded with ease, but considering that most of the information that will be going back and forth is likely to be of highly technical nature, the written record is by far the most accurate.

For truly short-range communications, such as we will find in the orbital station-to-earth link, both audio and teletype systems should be employed. Anyone who has ever listened in on an airport tower frequency must have been appalled at the amount of rapid chatter that goes into the business of getting planes into the

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air and back down again. Such chatter cannot be handled by teletype or any of the slower forms of transmission. I have a feeling that the orbital station radio center is going to be loaded twenty-four hours every day with requests for information about climatic conditions over Hawaii, requests to relay such and such to Alaska, and information and reply and so on. Voice radio is the thing for this.

And, of course, as each spacecraft rises out to the station level it will go on short-range radio, voice modulated, while the ship is matching velocity, course, and orbit with the station. The picture in the end-papers of the book 'Across the Space Frontier' shows the arrival of a rocket, the orbital station, the space telescope, and a couple of space taxis, along with several men in space suits. Since it is virtually impossible to handle a four-oar rowboat without a lot of chatter, the short-range radio is going to be a busy channel.

The ship-to-ship communications in fleet operations will be conducted in voice. Radio equipment like the current handy-talky that weighs about eight pounds will serve admirably. I have used such equipment over a distance of several miles, and I feel that in free space the range might be extended somewhat. This should be adequate. A fleet of three spacecraft heading for the moon should never get much more than a mile or so of one another. Therefore the light equipment should do the trick.

This same equipment will also be included as standard for all space suits. Two men out in space on the hull of a ship will be using such radio even though they are standing only a few feet apart. The use of cables and plug connections for close-quarter operations has been suggested, but I cannot see why a cable-reel weighing a half dozen pounds, plus the nasty tangle of wires, would justify itself, especially when the suit must have radio gear anyway.

Long range ship-to-ship is another thing that I cannot justify. I fail to see why it should be necessary for a ship en route to Venus to get in touch with another ship heading for Mars. Yet if this should become necessary, the way to do it is to relay the message from ship to earth to ship. It would be far easier because the earthside station will be keeping its antennas trained on both ships all the time, whereas it might be difficult for one ship in space to aim an antenna at another ship in space. Furthermore, the second ship, not knowing that the first wanted to call, would not have its receiving antenna trained on the first.

Yes

I have not mentioned transistors in this talk because the use of transistors is a foregone conclusion. Transistors will be used whenever they fill the bill for two reasons. One of the reasons is the matter of power requirements. Transistors

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drink up a lot less power than vacuum tubes. They are lighter and smaller. Since transistors can be made to do almost anything that a vacuum tube can do, naturally we will use them. However, the heavy-duty power transistor lies still in the future, and I anticipate that we will stick to the magnetron to generate our microwave power.

I have one suggestion to make to the designers of space stations and spacecraft. It would seem that both schools have included some sort of solar heat gadget for system power. The mercury boiler system, heated by a mirror from the sun, has been drawn in carefully in the book 'Across the Space Frontier,' but frankly I have a better suggestion. Just forget the mirror and run your mercury through a heat exchanger located in the radio equipment and do both jobs at once. A three centimeter magnetron in a radar equipment delivers both a wallop of power and enough heat to warm a four-room house. I think that the big problem is to get rid of the heat instead of collecting more of it from Sol.

And so in conclusion, we can assume that radio communication will not find the astronomical distances an insurpassable barrier, and we need not envision a monstrous installation pouring millions of kilowatts into the sky. We can take pride in saying that the interplanetary network could be set up today if we had someone at the other end to receive the signals.

I also have little doubt that by the time we get someone out there to receive radio messages, the art of communications will have taken another step forward and these carefully made suggestions will have become obsolete.

George O. Smith - Biography

George O. Smith has been active in radio engineering for 18 years. His experience covers all phases of the design and development of home radio and automobile receivers as well as phonograph and television equipment. During the war years, Mr. Smith worked on several projects, including the proximity fuse, radar, and submarine detecting gear. He was appointed Chief Components Engineer of the Emerson Radio & Phonograph Corporation in April, 1951.

Mr. Smith's discussion of the problems of interplanetary communication are the result of combined professional experience and personal interest and study of the conditions we expect to realize in space travel.