Wireless across space

Communication with possible intelligent beings on planets of other stars

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When the Viking lander-orbiter spaceprobe reaches the planet Mars in July 1976 we may receive the first confirmation that life exists not only on Earth but on extra-terrestrial bodies as well. It is extremely unlikely, however, that we shall find *intelligent* life either there or on other planets in the solar system. On the other hand, it is statistically likely that among the 10^{11} stars constituting our galaxy (the Milky Way) many have planets which are inhabited by intelligent beings of one form or another and at various levels of social and technological development.

As yet we know of no physical principle which suggests that space travel at speeds faster than light can be implemented. The distances between stars are enormous. The star nearest to the sun is 4.29 light-years away, a distance of a quarter of 10^{14} miles and nearly ten thousand times our distance from the outermost planet of the solar system. While interplanetary travel could be possible within fifty years, launching interstellar spacecraft, whether manned or unmanned, will at best be grossly inefficient, even after all the technological advances we can foresee have been achieved. Communication by electromagnetic waves will remain the most convenient and fastest method of making contact between stars. It is also the cheapest, requiring only the expenditure of electrical power, granted that the antennae and associated electronics used for transmission and reception exist already. Using 1970s technology and prices, a ten-word telegram costs less than 10 pence if the antennae are 45 metres in diameter and 10 light-years apart [1].

Extra-terrestrial civilisations could possess technology much more advanced than ours and make use of telecommunication means which we cannot implement (modulation and demodulation of gravitational waves or neutrino beams, etc.) or cannot imagine. But they would understand that, while some civilisations on other planets could be still more advanced than themselves, some could be behind them. Counting from the dating of the earliest known fossils of living things on Earth, we have been evolving for three thousand million years, and radio technology has been with us for less than a hundred years. Hence, to maximise the chance of achieving contacts, as primitive a communication technique as possible should be used by civilisations; this I shall call the "principle of presumed modesty". That is, every civilisation in attempting communication will try to make things as easy as possible for the other side, irrespective of whether the other side is in fact very advanced, because it does not know beforehand one way or another. Assuming that everywhere technology develops in the same overall sequence [2], we need therefore consider only radio communication.

Fig. 1. The radio telescope at Arecibo, Puerto Rico. The paraboloidal reflecting dish, 300m in diameter, is constructed within a natural valley in limestone mountains. The feed is supported 137m above ground by cables attached to three pillars. By moving the feed the telescope is made semi-steerable (at 1.42GHz, to any direction within 20° from the zenith).

Feasibility of interstellar radio communication

Our first television broadcasts took place at Alexandra Palace, London, nearly forty years ago. Within a distance of twenty light-years of our sun there are about a hundred stars and star components. It is not absolutely impossible that they all possess planets, on which there are civilisations who have built radio receivers sensitive enough to pick up those television transmissions. The people who sent out the television programmes, may therefore expect at any time now "replies" from up to a hundred different directions in the sky!

Returning from such speculation, we now show that indeed we already possess radio equipment capable of maintaining point-to-point communication with a planet of another star. Its technological advancement need be no higher than ours. (If it is more advanced the issue does not arise at all.) There is a definite low-noise "window" for the reception of interstellar radio signals, in the microwave region from 1 to 10 GHz (u.h.f. to radar s.h.f.). The window is determined on the low-frequency side by the onset of intense radio frequency cosmic radiation and on the high-frequency side by that of atmospheric thermal noise. As far as we are concerned, if the interstellar radio station is built on the moon, then the upper frequency limit will be extended to the infra-red, where absorption by dust and debris in the interstellar space begins to be serious. By the "principle of presumed modesty" we should ignore this possibility. Further, the atmospheres of planets where life has evolved to advanced forms must have similar constituents (oxygen and water vapours) and therefore similar noise characteristics.

We now derive an equation for the maximum range of radio communication. If the transmitting antenna radiates a total power P_1 over a bandwidth Δf in all directions with equal intensity, then from a distance l away the power received by an antenna of "effective" area A_2 will be

$$P_2 = P_1 A_2 / (4\pi l^2)$$

When l is of the order of interstellar distances, it is obvious that with reasonable values of P_1 and A_2 (reasonable by earthly standards), P_2 will be far too small to be detectable. However, the transmission can be beamed and made highly directional. If then a radio telescope with a parabolic reflector is used, there is a gain over the isotropic radiator of [3]

$$G_1 = \pi^2 (d_1/\lambda)^2$$

where d_1 is the diameter (aperture) of the reflector dish and λ the operating wavelength. (For simplicity it is assumed that it is radiating "uniformly", otherwise a numerical coefficient slightly less than 1 has to be included.)

Likewise, the receiving antenna will be a parabolic type and will have a gain G_2. If its aperture d_2 is large, as should be the case, its effective area is close to the physical area:

$$A_2 = d_2^2 \pi / 4$$

If now P denotes the minimum detectable signal power at the receiver, and L the maximum range of communication, which we want to find, we can write

$$P = P_1 G_1 A_2 / (4L^2)$$

$$= (\pi^2 / 4^2)\, d_1^2 d_2^2 P_1 / (L^2 \lambda^2)$$

$$\text{so that } L = \frac{\pi\, d_1 d_2}{4\ \lambda} \sqrt{\frac{P_1}{P}}$$

P will depend on the background and receiver internal noises, characterised as noise temperatures[4]. Without going into the details we can reasonably take P as 3.2×10^{-24} watts per hertz. Within the window mentioned earlier the interstellar background noise[4] is nearly constant at 3.2×10^{-22} watts per hertz (except at a few specific frequencies like 1.42GHz). In addition, since the receiving radio telescope will be pointing towards a star, microwave-frequency radiation of the star will add to this noise. However, if the star is more than ten light-years away it will be quite negligible[30]. By using masers or parametric amplifiers, and signal processing techniques such as time integration, frequency cross-correlation[5] and phasor detection[6], it is possible to dig out signals which are as much as 20dB weaker than this constant noise.

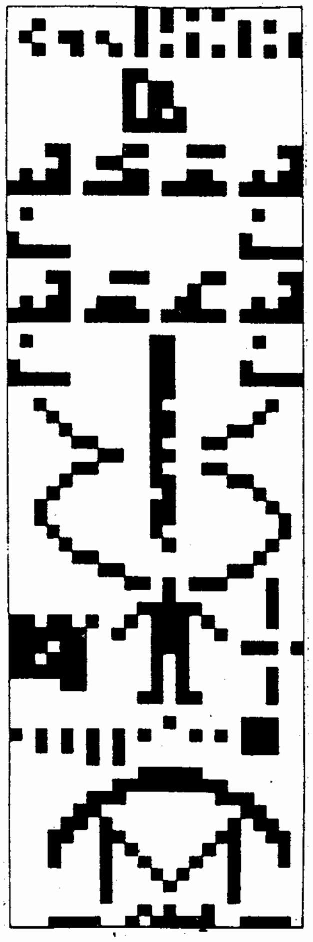


Fig. 2. Earth's first message to the stars (from ref. 23). The first bit sent is at the upper right-hand corner. The sequence continues from right to left and down.

Now, let us assume the receiver passband has been adjusted to be the same as the signal bandwidth Δf so that P in watts is $(3.2 \times 10^{-24} \Delta f)$, with Δf in Hz. Take λ representatively as 10cm, corresponding to a frequency of 3GHz. Further, assume d_1 and d_2 both to be 300m, the same as the aperture of the Arecibo radio telescope (Fig. 1) which is the world's largest in operation at present, so that $G_1 = G_2 \approx 80$dB. Then if P_1 is 0.25MW, the present limit in our technology, a little arithmetic will show that

$$L = 2 \times 10^4 / \sqrt{\Delta f} \text{ light-years}$$

The interested reader can draw graphs of L against P_1 for various values of Δf, at selected values of λ and ds. If one uses log-log scales they will be straight lines of slope -0.5.

It is seen at once that a larger L is obtained with a smaller Δf, though not quite proportionally. This is because reducing Δf diminishes the background noise power. Δf is limited by the frequency stability of the local oscillators of the transmitter and receiver, as it must be larger than the frequency drift. Using state-of-the-art quartz crystal oscillators and phase-locked loop systems for subsequent frequency up-conversion, Δf can now be made as small as 0.1Hz on s.h.f. waves. If this value of Δf is adopted, L is more than sixty thousand light years. In other words, two Arecibo-class radio telescopes, placed almost anywhere in the galaxy, could maintain communication with each other.

Problems and solutions

Interstellar radio communication is not, however, without problems. The first few concern Δf. The maximum amount of information obtainable from a radio transmission lasting a period of time t is, in bits,[7]

$$I = \Delta f . \log_2 (1 + \alpha) . t$$

$$\approx \Delta f . \alpha . t / \log_e 2$$

$$\approx (3/2)\, \Delta f . \alpha . t$$

where α is the received message signal-to-noise-ratio and is assumed to be small. As an illustration, to send 3 megabits, which is the average amount of information contained in one book [8], to be received up to points where α is 1, then if Δf is 0.1Hz time t will be nearly 8 months. Unless we merely want to transmit call signals, which are of low I and serve only to advertise our existence and that we send call signals, then the chosen Δf cannot be too small so that the transmission time t will be reasonable. Moreover, signals of low I may be mistaken to be not artifical but of natural origin [9]. Here it is interesting to note that when the stellar objects called pulsars were first observed there were speculations that they were radio beacons for interstellar navigation – but their emissions pulse with extremely regular periodicity and nothing else. The speculations did not last long.

Also, on the receiver side, the time-constant of the passband determining filters is set to be $1/\pi\ \Delta f$. If Δf is very narrow the time τ_i required for a single signal recording (the "integration time") becomes inconveniently long, especially if the signal-to-noise-ratio is low.

More importantly, in the frequency domain, reducing Δf increases the total number of possible channels. Communication is achieved, of course, only if both the transmitter and the receiver are tuned to frequencies within the same channel. The trouble is that each side is ignorant of the other's choice of frequency before the contact. Within the 1 to 10 GHz window there will be nine thousand channels if Δf is 1MHz, but ninety thousand millions if it is 0.1Hz.

Fortunately, this problem of frequency compatibility seems to be tractable. Within that window there are particular frequencies which have special significance. Although each civilisation does not know beforehand how the others think, to maximise the chance of contact each should in its planning converge on those points which can be identified by all the others; this has been referred to as the "principle of anti-cryptography".[10] For us, the first such "watch frequency" to be so identified is the 1.42040575GHz spin-flip emission line of neutral hydrogen. As a physical property of matter, its value is universal and known by all other civilisations. Its significance comes from the observation that hydrogen is the most abundant element in the universe, so that it may be regarded as one fundamental constant of nature. However, for the same reason, it is unusually noisy. There has been a suggestion that its second harmonics (2.84GHz) should be chosen instead.[11] Also suggested [12], later, are the 1.667358 GHz radio frequency line of the hydroxyl radical and two "naturally" derived frequencies in the "water hole"[13] between it and the hydrogen line. (Water is composed of hydrogen and the hydroxyl radical, and it is most probably the basis of life anywhere in the universe.) All these frequencies lie near the low-frequency end of the window, an additional advantage since $L \propto 1/\lambda$.

There is an analogous problem in the time domain – the synchronisation of the transmitting and the receiving radio telescopes. As mentioned earlier, high gains on the telescopes, and therefore longer L, are obtained by making them highly directional. Hence, they are at one time transmitting or listening to only some small solid angles in the sky – in fact, $(4\pi/G)$ steradians, where G is the gain of the telescope concerned. (The whole sky extends by definition 4π steradians.) For communication to be achieved the two telescopes have to be in the same line of sight and pointing at each other. The probability of this happening by pure chance is $(1/G_1G_2)$. If G_1 and G_2 equal 80dB, it becomes 10^{-16}, an exceedingly small probability. (A field of view of $4\pi/10^8$ steradians is so narrow that generally at most one star lies in it.)

One solution is to reduce G_1 and G_2, which however decreases L as well. Another solution is the simultaneous use of vast numbers of transmitting and receiving telescopes, pointing in different directions. Practical proposals are not lacking [14]! Even if neither is feasible, the problem may still turn out to be solvable. In the same way that certain frequencies are special and, obviously to all, should be those used for interstellar communication, some astronomical phenomena in the galaxy may be suitably exploited as "time markers" and used for synchronisation purposes. One example is, for binary stars (two suns circling each other), the times when the two stars are nearest and farthest away [15]. Another, I propose, is the occurrence of a supernova[16] (a star "blowing up"; and this is, incidentally, the event responsible for the generation of the heavy chemical elements and the cosmic rays which in turn are requirements for the appearance and evolution of life.)

After the interstellar signals have been located, yet another problem is presented by the demodulation process. Which modulation method has been used by the transmitting civilisation? For reasons of simplicity and obviousness, the information must have been in binary form. **According to one analysis[10], the optimum binary modulation process (and by "the principle of presumed modesty" the one to be used) is by sense-switching of the circular polarisation of the radio waves. This means that the waves will be circularly polarised, in the clockwise and anticlockwise directions alternatively to represent 0 and 1. To use amplitude, frequency or phase modulation will be less efficient.**

Assuming that we have got the message (as a sequence of 0s and 1s), we have to start decoding it into intelligent information. Much has been discussed about this subject of "interstellar cryptography". The information may be pictorial as was the first interstellar transmission by us (see later: Fig. 2). It may be more sophisticated and high-level, and it will not be so straightforward to interpret and translate into our own concepts. However, the transmitting and the receiving civilisations share quite a few things in common, irrespective of their differing systems of concepts (which in any case all reflect the same objective world). They are the message itself, the "same" understanding of physics (albeit with different "names,,' notations and unit systems), and the (universal) conception of arithmetic (counting one, two, three, etc.). A language of high expressional power can be defined, starting from them and nothing else. A long message can consist of, in the first part, the construction of such a formalised syntactic language, followed then by "books". The reception and deciphering of such a message will have unimaginable effects.

Lastly, there are a few "tactical" problems. The transmitting and the receiving planets will be rotating as well as travelling in space, so that they are moving relative to each other. Hence, there will be a time-varying Doppler shift in the signal frequency, equal to the (varying) relative velocity divided by the speed of light. However, this can be eliminated easily if each side separately compensates for its contribution to the total shift, by using for example a phased frequency-scanned antenna system [17]. Another problem is due to the fact that interstellar space is not exactly a vacuum, so that dispersion of the radio signal occurs. The lower frequency components of the signal have slightly lower propagation velocities, resulting in distortion. However, with an unusually small Δf, it will not be serious unless the propagated distance is very large ($>10^4$ light-years).[1]

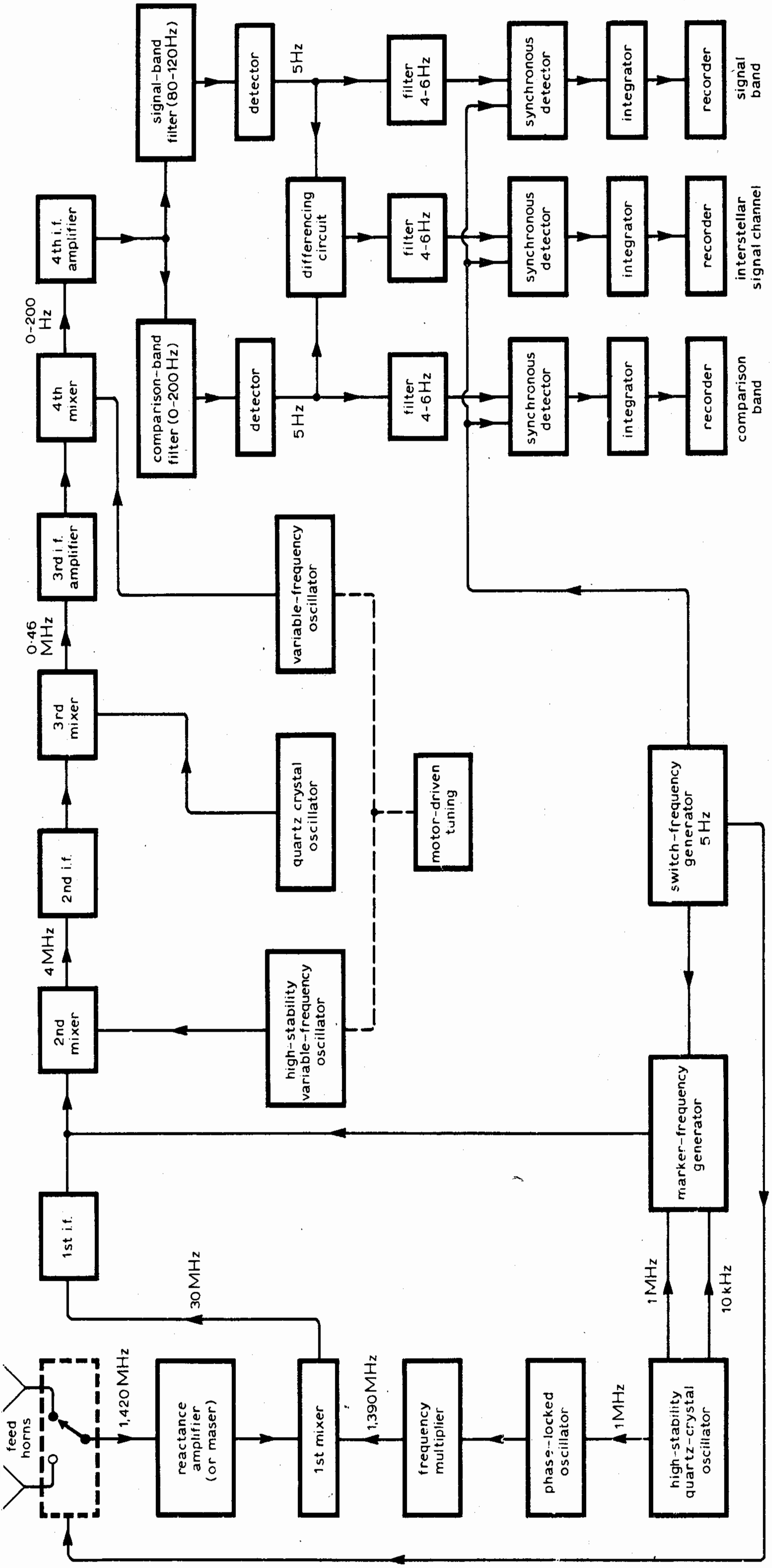
The receiving system

Let us now consider the radio telescope receiving system (sometimes referred to as a "radiometer") in some detail. Its basic function is to amplify, within a specified bandwidth at a selected frequency, the signal-carrying electromagnetic waves collected by the telescope. After appropriate demodulation the signal drives an output recorder.

Its front end will consist of a low-noise pre-amplifier – inevitably a parametric amplifier or the more expensive liquid-helium cooled maser [18] – which is usually placed right in the telescope to reduce feeder transmission loss. (A discussion of "noise temperature" and front-end amplifiers can be found in reference 4.) To eliminate misleading outputs due to internal drift in the system characteristics, the input to the pre-amplifier is switched between the telescope feeder and a standard noise source. The pre-amp is followed by several stages of superheterodyning intermediate-frequency amplifier, and

Investigator	Observatory	Frequencies	Targets
Troitsky	Eurasian network, USSR	0.6, 1 and 1.875 GHz	Entire sky
Zuckerman, Palmer	Green Bank, USA	1.420 GHz	Some 600 nearby sun-like stars
Kardashev	Eurasian network, USSR	Several	Entire sky
Bridle, Feldman	Algonquin Radio Observatory, Canada	22.2 GHz	Several nearby stars
Drake, Sagan	Arecibo, Puerto Rico	1.420, 1.653 and 2.380 GHz	Several nearby galaxies

Fig. 3. Project Ozma receiving system schematic (adapted from National Radio Astronomy Observatory diagram).



then by the detector, which is synchronised to the pre-amp switching frequency, so that signals from the feeder which are pulsed at the same frequency will be demodulated but receiver noises etc. which are not will be ignored. An integrator comes after the detector stage. It averages the signal over an interval τ_i equal to its set time-constant, to give successive recordings. The root-mean-square deviation in a single recording is inversely proportional to $\sqrt{\tau_i \Delta f}$, so that a longer τ_i leads to more significant digits in the reading. In the search period, before the signal has been detected, square-law (energy) detectors are used. After the signal has been found, however, a coherent or homodyne detection method is used to retain the phase information. The recordings usually go through analogue-to-digital converters and then are stored on tapes, to be dumped into a computer later. Sometimes, signal processing processes such as frequency-correlation are performed in real time immediately after the integrator, by a digital correlator[19].

The first attempt by mankind to listen for extra-terrestrial radio messages (Project Ozma) was made fifteen years ago.[20] In the last five years there were three more publicised searches.[21, 22] Project Ozma used a telescope of $d=26$ metres, and searched at frequencies from 1.4202 to 1.4206GHz with Δf from 40 to 100Hz. The other three had d ranging from 26 to 50 metres, frequencies at 1.420 and 0.927GHz, and Δf at various values from 13Hz to 2MHz. Results were all negative, which is hardly surprising as these efforts were on very small scale. Using the Arecibo radio telescope ($d=300$m) the first radio signalling to other stars was carried out in 1974, just before the first man-made objects to leave the solar system would have left. (These were the Pioneer 10 and 11 space-probes, travelling more than a hundred thousand times slower than the radio signals.) The radio message[23] has 1,679 bits and therefore can be broken down into a two-dimensional picture in only two ways, either as 73×23, or as 23×73 which is the intended one (Fig. 2). The frequency of transmission was 2.38GHz, Δf was 10Hz and the transmission time lasted 169 seconds. Binary frequency modulation was used, the effective average power was 3×10^{12}W, directed towards the Great Cluster in Hercules, a group of some 300,000 stars 2.4×10^4 light-years distant. The Doppler shifts in the signal frequencies due to motions on the Earth side had been continuously compensated.

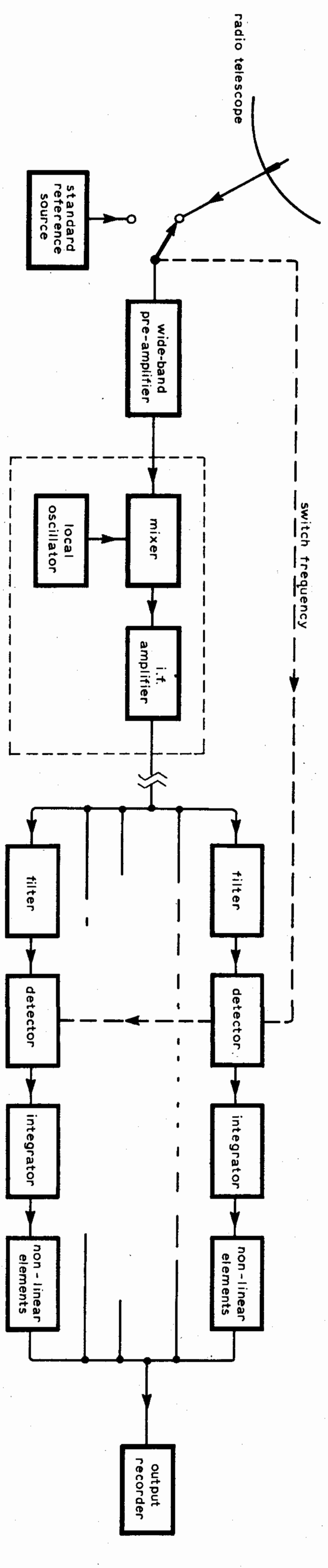


Fig. 4. Multi-channel receiving system

The functional block diagram for the receiving system used in Project Ozma, which will be representative, is shown in Fig. 3. Two horn antennae are connected by waveguides to an electronic switch, and the signals from them are fed alternately to the pre-amplifier. They are placed above the telescope reflector dish, so that one "looks" effectively at the star of interest and the other at a point in the celestial sphere just next to it. The second horn serves as a comparison noise source. The detectors on the right-hand side of Fig. 3 respond only to signal pulses synchronised with the switching frequency. In this way receiver internal drifts, and terrestrial interferences which are collected by both horns, are eliminated, since they are not synchronised.

The quartz crystal oscillator for the first mixing stage is kept at a very stable temperature in an oven-within-oven, and has a frequency drift of less than 1Hz in 1GHz. Its output is up-converted in frequency to 1.39GHz by a phase-locked loop system.

After the fourth i.f. amplifier, two filters pick up one broad (0-200Hz) and one narrow (80-120Hz) band of signals. Their attenuations are in the ratio of 5 to 1, so that if the signals are broad-band their outputs are the same. In this case, the differencing circuit and thus the "interstellar signal channel" will have zero output. (The signal-band filter is shown as passing a Δf of 40Hz, but it can be easily and quickly re-adjusted and in the actual experiment Δf had varied from 40 to 100Hz.) Only when there are signals of bandwidth less than 200Hz will the filters' outputs be different. The other two outputs, shown as "comparison band" and "signal band," serve as checks on system performance.

The other receiving systems used in the search for extra-terrestrial radio messages are similar in construction, except that they are multi-channel so that a number of watch frequencies can be scanned simultaneously. Fig. 4 is a schematic of these systems. There is the radio telescope, and a standard reference source for noise comparison purpose. After going through the switch and the wide-band pre-amplifier, the signals pass several stages of mixers and i.f. amplifiers and are then selectively allowed through a number of pass-band defining filters. After detection and integration they are summed by non-linear circuit elements and go to an output recorder. Multi-channel one-bit digital correlators[24] are also sometimes incorporated. Each channel can be searched individually, and the data from several adjacent channels can be combined to represent a wider channel without any loss of information or sensitivity.

(It may be interesting to compare the receiving systems just described with a home-made one operating at 0.2 and 0.45GHz and for less sophisticated purposes[25], which, while being much simpler, contains all the essential ideas.)

To be continued

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world

Myths and maths

Why should scientists want to get in contact with possible intelligent beings in other solar systems? The author of "Wireless across space" in this issue does not set out to answer this question – he is writing a technical article. Yet the question is a legitimate one to ask. Much time, money and effort has been expended on this work. One answer could be in the "because it's there" category – the possibility exists, so we must take up the challenge. Another answer could be scientific curiosity. Science is part of university life – which is justified by education and passing on the culture – and science needs problems to work on. The psychologists might suggest that we have an inner wish to find life elsewhere: we are really seeking more evidence to demonstrate purpose and design in the universe, to reasure us that life on this planet is not just an isolated molecular accident.

Practical people will say these are specious answers. But when you try to find the basic motivation behind so much of our science and technology you find yourself among similar, apparently vague and mystical explanations. Technology, in particular, is supposed to serve the needs of man (such as for more communication channels). But the needs of man, beyond those of sheer survival, are largely generated by his visions of himself – in fact by myths. (Here "myths" is not intended to mean things that are not true, but expressions of ideas by which we act and live.)

Behind much of technology is the myth of human progress – that we are on some road that will eventually lead us to perfection if we work away hard enough at our gadgets. And there are also myths of perfection operating in the specialized areas of our progress. Take sound reproduction, for example. Frequency and phase response, harmonic and intermodulation distortion, signal-to-noise ratio and so on are ultimately all measurements – nothing more than meter deflections and points plotted on paper, symbols representing concepts. Yet those of us who feel we cannot rely on our own ears believe that if we make all the measurements absolutely right by sufficient expenditure of money and technical effort, the reproduced sound must necessarily be absolutely right also. This is an example of the myth of objectivity.

Technologists and scientists should always be aware that objectivity is a myth. It is so easy to fall into the trap of imagining that the laws of nature, of logic and mathematics somehow exist independently – that they existed before anyone was around to think them. As the eminent molecular biologist Jacques Monod points out in his book *Chance and Necessity*, the principle that objectivity is necessary for truth is in fact an ethical, and therefore wholly human, decision. Our myths and maths go hand in hand.

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2 — Proximity of communicating civilizations in the Milky Way

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That communication with extraterritorial intelligence (sometimes abbreviated to CETI) is possible with today's radio technology was postulated in Part 1. As further support of the thesis, we will now consider an order-of magnitude calculation of the most probable distance separating a civilisation from its nearest neighbour, using today's knowledge and opinions.

There are at least 10^{10} galaxies, some containing more and some less stars than the Milky Way, in the part of the universe so far observed. But for our present purpose we need only to consider our own galaxy, the Milky Way (Fig. 5), which from statistical star counts has some 10^{11} stars. (On the scale of galaxy diameters intergalactic distances are two orders of magnitude higher.) After Drake[5], the number of civilisations which have the capacity for interstellar communication can be analysed as

$$N^* = Rf_p n f_l f_h f_c T$$

Here R is the average rate of star formation. The age of the Milky Way is about 1.5×10^{10} years, and thus the overall R will be seven stars per year. However, the actual R in earlier times must have been larger, and in later times smaller, while those stars formed in the earlier periods are likely to be lacking in heavy chemical elements and should be excluded because in their absence advanced civilisations or perhaps even life itself cannot arise. In view of this, a reasonable value of R will be one star per year.

f_p is the fraction of stars possessing planets. For a long time it has been observed that stars whose temperatures are similar to or less than that of our sun – and nine out of ten stars belong to this category – are usually rotating much less rapidly than the remaining stars; the observation is deduced from the much smaller amounts of the Doppler broadening in their spectral lines. The interpretation is that they have planets to which most of their rotational energies have been transferred. Furthermore, in particular, the motions of some nearby stars, "Bernard's Star" for instance, have been seen to "wobble," and this almost certainlv shows that they have dark companions (planets) in orbit around them.[26] The mechanism of planet formation is not yet well-established theoretically [27] but in all possibilities it is consistent with that of star formation, viz. the self-gravitational collapse of a nebula of gas and "dust" into a state where it is hot and dense enough for the start of nuclear reactions and the birth of the star. We shall be conservative by taking f_p as 0.5.

n is the mean number of planets in each planetary system which have environments suitable for life; or, in astrobiologists' jargon, which lie within the ecosphere of the local sun. The most important factor here is whether the planet in question acquires by outgassing its crust an atmosphere which initially contains hydrogen but not oxygen (where complex molecules when formed will not be at once oxidised) and a hydrosphere of water. In our solar system Earth and Mars satisfy the conditions, and we shall use 2 as the value of n, by the "assumption of mediocity"[11] (that what is true for us cannot be unique and is likely to be the average for the whole galaxy).

f_l is the percentage of these planets in which life does develop. It looks to us that the abiogenic (spontaneous) synthesis of probionts (self-replicating molecular assemblies) is, given the boundary conditions of a primitive hydrosphere containing hydrogen, methane and ammonia, forced by the laws of physics and chemistry and therefore a certainty. Given, in addition, sufficient time and an environment which is not entirely static, self-reproducing organisms are bound to appear later. (Incidentally, I mention the speculation that the properties of matter or even the physical laws change, until they are such that the appearance of life in the universe becomes inevitable. We should therefore not be surprised that everything seems to just fit in, so that in particular we exist on earth, because when it is not so we do not exist to know. We are here, hence the world is being such that life can exist – the "anthropic principle"; and hence there is life "out there" as well – the assumption of mediocity.) It follows that f_l is very nearly 1 and as a close estimation is taken as 1.

f_h is the fraction of inhabited planets in the biospheres of which life advances to a high level, during the lifetime of the local sun. A high-level life form means one which will not become an evolution cul-de-sac. It is, I think, one which can form an internal analytical model of the external environment, *and* which relies mainly on this ability for the survival of its species (or, more exactly, its genes). On earth this occurred when the first truly erect walking species, *Sinanthropus pekinensis*, appeared; that was 1.5 million years ago, according to the very recent fossil dating by R. E. F. Leakey. Ample artefacts have been uncovered to show that they were tool-using and relied more on manipulative skill than on structural adaptations of the body for species survival. We have, or at least think that we have, reasons to suppose that, given certain broad and fairly general initial conditions, the appearance of such species in due course is again a certainty. Of course, there are many hurdles to jump before its superiority over other species, many of which are splendidly adapted to specific environments so long as they do not change, becomes established (as is so for us, *Homo sapiens*). Some species (e.g., the *Neanderthal man*) failed and went extinct. However, eventually one species would succeed. This is not so only if, for example, the planet is covered entirely by water, so that there is no land for life to invade from the sea and to develop stronger interactions with the environment. From these considerations a guess of f_h will be 0.5.

f_c is the fraction of planets populated by higher forms of life, on which civilisations develop to the stage of participating in interstellar communication. That is, they change from "planetary" civilisations (civilisations whose activities and modes of thinking are restricted in their scopes to their own planets) to extra-planetary civilisations. This is precisely the threshold over which we are about to step, and it is difficult to imagine that we will somehow regress. My considered belief is that similar laws of technological and social evolution apply in different planets, except where the natural conditions differ fundamentally. Lower life forms can be very unalike on different planets or even on different regions of a planet, because of the multiplicity of planetary initial conditions and of evolutionary accidents. However, as they evolve further, the influences of these boundary conditions decrease in proportion to those dictated by the universal laws of nature. Accordingly, the "psychologies" of different intelligent races should in general converge. With the conservative assumption that the development of a technological civilisation requires that things like low melting-point alloys and easily accessible fossil fuels are naturally existing, we take f_c as 0.2.

Finally, T is the lifetime of the communicative stage of these civilisations. In our view the *continued* development and progress of a technologically advanced civilisation depend on its social system, which is a matter of experimenting and choice, so that they are not only possible but probable because presumably they are its intentions. We then judge that, say, one out of ten civilisations lasts as long as the local sun remains "healthy." The averaged value of T will be 10^9 years.

With these values, N^* comes to be $(1\text{year}^{-1}) \times 0.5 \times 2 \times 1 \times 0.5 \times 0.2 \times (10_9$ years) $= 10^8$. In other words, on average one out of a thousand stars will possess on average one planet where there is a civilisation in the interstellar communicative stage. The main uncertainties in this estimation of N^* lie with the last three factors, namely f_i, f_c and T.

Using the mean density of stars in the Milky Way, which is 1 star per 200 cubic light-years, the mean minimum separation of communicating civilisations (i.e., the most probable distance between the nearest neighbours) will be the radius of the sphere of volume 2×10^5 light-years, or roughly 40 light-years. In general, the distance is $2 \times 10^4/{}^3\sqrt{N^*}$ light years.

If direct radio contact is considered, the civilisations have to exist in the same epoch. A slightly more complicated procedure gets $23/{}^3\sqrt{T_G/T}$ light-years as the likely minimum separation between 'contemporary' civilisations,[28] in which T_G is the galaxy time-scale, i.e. 10^{10} years. In our estimation therefore it will be about 50 light-years. This is not much greater than the previous estimation of 40 light-years, because we have taken T to be not much smaller than T_G. A more exact assessment will have to take into account the length of time required in biological evolution [29] but being much less than 10^9 years it can be taken as zero.

The chance that a randomly selected star is sending interstellar signals is 0.001. If and when the synchronisation problem referred to previously has been solved, we can be sure that, when we look at it, its signals are beamed towards us. In this case, the probability of achieving at least one contact after searching N stars is $1-(1-0.001)^N$ or approximately $1-\exp(-0.001N)$. A search of a thousand stars will, assuming perfect synchronisation, give us a 63% success.

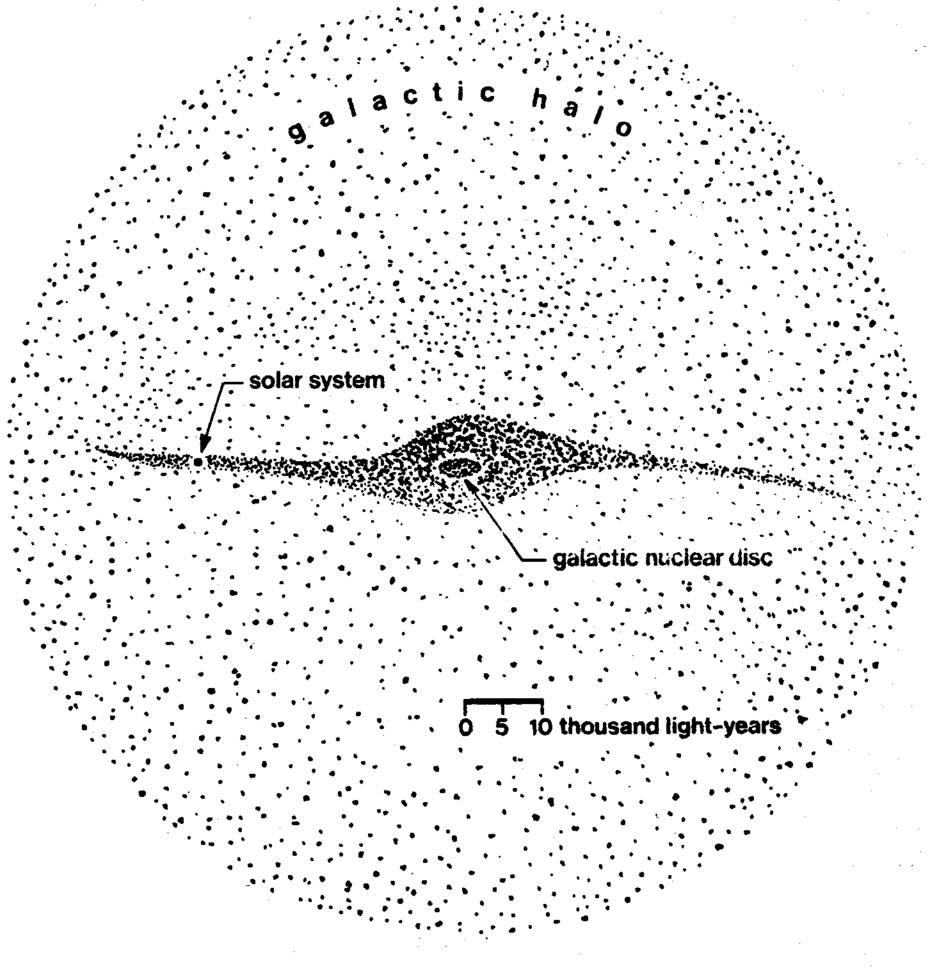

Fig. 5. Schematic picture of the galaxy, showing its shape and size and the relative position of our solar system.

Inevitability of participation in interstellar communication

The feasibility of intentionally achieving communication by radio contact with extra-terrestrial civilisations has been shown. By way of conclusion I would point out one more consideration. We have been using u.h.f. radio communication for some fifteen years. Also, there must be now a few thousand television stations on our planet which transmit in channels 14 to 83 at a power of something like 20kW on average, and a lot of u.h.f. transmitters such as maritime radio beacons and satellites' telemetry and tracking. Earth is then radiating nearly a tenth of a watt per hertz into space at centimetre wavelengths. By the equation for L, we see that these radiations can be detected, over a distance of 50 light-years, by a radio telescope of effective area 40km^2 and listening to a bandwidth of one hertz. If there is such a telescope on a planet within this distance, the discovery of our presence in due course, whether we intend it or not, is highly probably.

To build this telescope does not necessitate fantastic technological sophistication. In fact, as investigated in the Project Cyclops [30], the construction by us of a phased antenna array of ten thousand parabolic reflectors, each 30m in diameter, is feasible (it would cost six to ten thousand million dollars but this is less than half the cost of the Apollo space programme.) Such an antenna system would have an effective area of 20km^2, and there appears to be no technological limitation to its expansion, to a size of 100km^2 or more. If we do build this colossal telescope, we will be able to eavesdrop on our neighbours. (A further feasibility study after Project Cyclops is being undertaken, and should be completed by summer 1976.) The Cyclops concept is already the basis of a very-large-array telescope now under construction in the plain west of Socorro in New Mexico. When completed, it will have 27 parabolic dishes, each 30m in diameter, and an estimated sum of seventy-six million dollars will have been spent. Schedules for general radio-astronomical observations at 1.3, 2. 6 and 18-21cm wavelengths, it will be partially operating by the winter of 1977.

I have not discussed the rationality or even necessity of communicating with extra-terrestrial civilisations. Everyone will form his or her own opinion, and it seems out of place to argue here. However, [illegible] to me that it is [illegible] resources to seeking out life outside Earth, than to building things which potentially destroy life on Earth and which are no less expensive.

The table [31] published last month listed projects to detect radio signals from extra-terrestrial intelligence which are still in progress. The complete projected programme in the USSR has been published [32]; it is perhaps at present the country where (mainly for political reasons) such work is taken on most seriously.

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Some readers interested in CETI and related subjects may like to read, among other magazines and journals, Spaceflight and the Red Cover issues of *J.B.I.S.*, both published by the British Interplanetary Society.

Sixty Years Ago

The following piece was printed, without much comment, in our issue of July, 1916. It was in the section "Digest or wireless literature", which contains a couple of fairly imaginative accounts of inventions and development, including a description of a wireless-controlled boat of 30 tons, which carried a torpedo at 50 mph and would turn upon and destroy any jamming transmitter!

Radium and aerials

"The following abstract of an article by E. Leimer in the Elektrotechnische Zeitschrift, printed recently by the *Electrician*, will be of special interest to our readers as it contains a report of some experiments on new lines.

On the results of Szilard with radium-coated lightning conductors becoming known to the author he was led to consider the possibility that radium might exert some effect upon the reception of radio-telegraphic signals.

The first experiments were made with an indoor antenna consisting of a wood rod closely wound throughout its length with wire, the rod being directed towards a sending station, FL, about 300 km distant from it. This antenna was suspended in a room. The receiving set used comprised a galena detector, 4,000 ohm telephones, and a tuning coil 50mm in diameter, and having 800 turns of enamelled wire. No signals were audible from FL at any position on the tuning coil. Signals were, however, at once distinctly audible as soon as a sealed glass tube containing radium bromide of 50,000 units (and thus very weak) was brought near.