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Moderate Cost UHF Satellite Communications Without Exclusive Frequency Allocations

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ABSTRACT

Although UHF (225-400 MHz) operation can provide relatively low-cost satellite communications, the exclusive frequency allocations necessary for very simple systems almost certainly cannot be obtained. In this note a scheme is described which alleviates this problem, allowing co-existence between the current line-of-sight users of the UHF band and potential satellite users equipped with relatively inexpensive terminals.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

MODERATE COST UHF SATELLITE COMMUNICATIONS WITHOUT EXCLUSIVE FREQUENCY ALLOCATIONS

INTRODUCTION

The advantages of satellite communication to mobile users are by this time well known. At a minimum a satellite link can be viewed as a replacement for an HF link, offering a level of reliability far in excess of that achievable at HF. In addition, satellites permit a degree of flexibility in network organization not achievable using other media.

It is also clear that an important impediment to the widespread use of satellite communications for mobile platforms is systems cost, which tends to be dominated by surface terminal costs for practical systems employing hundreds or thousands of user terminals. The single most important component of a mobile terminal (particularly aircraft) from the cost point of view is the antenna and its pointing and tracking. It is because of this that the VHF/UHF region of the spectrum is so attractive. It permits the use of cheap, simple, essentially hemispheric coverage antennas without the need for pointing and tracking.

While use of the VHF/UHF band is a necessary ingredient for economic user terminals, it is not sufficient. The rest of the terminal, and in particular the modem possessing suitable sophistication for efficient satellite use, is at present excessively costly for widespread use. And even more important, the current heavy utilization of the VHF/UHF band by line-of-sight (LOS) links (particularly ground-air) has created a wall of resistance to potential satellite use by making it extremely difficult to obtain operational frequency allocations.

One approach to the economy problem has been suggested previously. Some of the heaviest users of the band are USAF ground-to-air links. A new family of LOS transceivers is being developed for eventual installation in all aircraft. If, at the outset, some minor modifications are made to these transceivers, then they can do double duty - LOS and satellite service. These modifications include incorporation of a low-noise preamplifier, improvement of frequency stability, and the provision of an IF interface for an external modem. A simple narrow band voice or data modem, hooked to the interface of the modified radio, would thus provide minimum cost satellite communications capability.

While this scheme has some attractive features, the employment of simple, narrow band modulation presents one severe problem: it is so highly vulnerable to interference from LOS users and it interferes so significantly with nearby LOS users, that exclusive uplink and downlink frequency allocations are mandatory throughout the coverage area of the satellite. The chances of obtaining these allocations, expecially worldwide, do not appear to be bright.

Accordingly, we have designed an alternative scheme which approaches the above scheme in economy but allows LOS and satellite users to co-exist in the same spectrum. The remainder of this note describes the essential features of this scheme.

GROUND RULES

The two most important boundary conditions imposed upon the terminal design have already been stated in the introduction:

1) Economy
2) Co-existence with LOS users in the same frequency spectrum.

Other considerations are:

3) Utilization of an upgraded LOS transceiver if possible.
4) Digital 75 b/sec operation.
5) Rapid automatic synchronization ($\leq$ 5 sec) without use of range or range rate information.
6) Reasonable detection efficiency; i.e., low required signal-to-noise ratio.

Condition (3) allows economies and saves space; the latter can be important in some applications. Condition (4) represents a small limitation; most of the applications can do very nicely with the low rate. Realization of a single, low-rate system can lead to important economies. Condition (5) is important for operational reasons. An overly long synchronization time is both inefficient and inconvenient. Synchronization time can be decreased by using position information. Unless this is done automatically, it can be operationally inconvenient. Condition (6) is governed by the desire for efficient satellite power utilization; the multiple access capability of a repeater is inversely proportional to the required signal-to-noise ratio in each user's receiver.

PRINCIPLES OF CO-EXISTENCE

A satellite communications terminal can co-exist in the same spectrum with a line-of-sight link if the mutual interference is sufficiently low. The four possible modes of interference are shown in Fig. 1. Interference paths 1 and 2 are the ways in which the satellite user can interfere with the LOS user; paths 3 and 4 are the ways in which the LOS user can interfere with the satellite user.

1. Interference with LOS Links

The satellite user transmissions interrupt the LOS user by the direct path (path 1) or via the satellite (path 2). Since the satellite is much further away from the LOS receiver than any desired LOS transmitter (and its signals are correspondingly weaker), the effect of interference via path 2 is negligible. Path 1 is important.

A signal from a satellite terminal can affect a LOS receiver in two ways. When a desired signal is present, the satellite user signal can act like noise and deteriorate the LOS receiver signal-to-noise ratio. If the LOS receiver is not receiving a transmission, the satellite user signal can trigger the squelch circuit and thereby generate an undesired receiver noise output.

LOS links use the spectrum in 100 kHz channels with channel utilization repeated every few hundred miles. Present plans call for the channel spacing to be reduced to 50 kHz in the United States in 1970. No such plans are known to exist elsewhere. The technique that we use to render the interference inoffensive is for the satellite user terminal to transmit within a given 50 kHz channel for a time T and then frequency hop to other such channels spread over a wide band W, returning to the original channel no sooner than a time $\frac{TW}{50\,\text{kHz}}$. Thus, if T = 2 sec. and W = 10 MHz, then the minimum time between successive utilizations of the same 50 kHz channel is 400 seconds or about $6\frac{1}{2}$ minutes. For T = 10 sec., W = 100 MHz*, this time is about $5\frac{1}{2}$ hours. Thus, in the first case, the LOS receiver receives an interfering signal lasting 2 seconds no more often than every $6\frac{1}{2}$ minutes; in the second case the interference lasts for 10 seconds and occurs no more often than every $5\frac{1}{2}$ hours.

The rates at which interfering signals occur are generally much lower than the bounds computed above. This is because the offending satellite user terminal is

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* Such bandwidths are technically feasible and, with spectrum sharing, are certainly not out of the question.

usually an aircraft who transmits sporadically and who may be out of line-of-sight of the LOS receiver after his first interfering transmission.

Even when interference does occur, the intelligibility of a desired transmission will often still be adequate at the LOS receiver output. If a message becomes garbled, a brief repeat will be sufficient.

2. Interference with Satellite Links

The satellite terminal receives interfering signals from nearby LOS transmitters many orders of magnitude greater than the expected signals from the satellite. (Path 4, Fig. 1). He endures them through a sequence of measures.

a. Since the satellite signal hops in 50 kHz channels over a wide band, say 10 MHz, an interfering LOS user will occupy the same channel for a fraction (say 1/200th) of the time. The filtering in the LOS receiver to which the satellite receiving modem is connected will greatly attenuate out-of-channel signals.

b. The demodulator is carefully designed so that interfering out-of-band signals cannot produce in-band signals from intermodulation distortion.

c. The satellite communications signal is hopped within each 50 kHz band it occupies. Our suggested structure calls for 6 subchannels 4.8 kHz wide in each 50 kHz channel over which the signal is hopped (Fig. 2). The information decision made by the demodulator averages over these 6 subchannels. Thus, if the narrowband interfering signal lies within one subchannel, the demodulator still has 5 unjammed chips (subchannel signals) over which it can make its decision.

SIGNAL STRUCTURE AND DETECTION

We have shown above that because of the mutual interference problem we adopt a frequency-hopping system in which fast-hopping (every 13.3 msec) takes place within a 50 kHz band with slow hopping (every few seconds) from band-to-band. A decision interval of 80 msec contains 6 chips. With 6 bits transmitted during this time, the data rate of 75 bps is obtained. The method of modulation is shown in Fig. 3. Every 80 msec the 6 bits define one of 64 possible frequencies to be transmitted during the next interval. These possible frequencies are equally spaced at 75 Hz (1/13.3 msec) intervals with 32 above and 32 below the "carrier" for each chip. The 64 frequency slots thus occupy a bandwidth of 4.8 kHz. Different carrier frequencies within the 50 kHz band are selected for successive chips.

Of course, there are other signal structures which will minimize the effects of mutual interference, but this particular structure is compatible with the bandwidth and tunability of a modified LOS transceiver.

A conceptual diagram of the demodulator structure is shown in Fig. 4. During each chip, the received signal is frequency analyzed with a bank of 64 matched filters tuned to the 64 possible modulation frequencies. The results of these analyses for the 6 successive chips in a decision interval are thereupon added incoherently. The largest sum identifies the most probable transmitted frequency (of the 64 possible) and the 6 bits corresponding to that signal are delivered to the user.

In the realization of Fig. 4, the slow hopping is removed by tuning the LOS receiver. Thus the signal to the demodulator has a 50 kHz bandwidth within which the fast hopping occurs. This signal is then converted to base-band in quadrature using a fast hopping local oscillator. The two signals thus obtained are limited, sampled and digitized. A discrete Fourier transform provides the required 64 channel frequency analysis.

The discrete Fourier transform technique permits fast operation of simple digital hardware to replace a highly complex bank of matched filters. Such a realization also provides time and frequency acquisition and tracking information at very low additional hardware cost.

ACQUISITION AND TRACKING

Clearly, this system requires synchronization information of three kinds. First, coarse time (~ 1-10 seconds) is required to tune the LOS synthesizer for the slow, wide-band hopping. Then fine time (~ 10 msec) and frequency (~ 75 Hz) are required to tune the fast synthesizer.

There are three steps involved in synchronizing the receiver and maintaining its synchronization.

1. Coarse time information for tuning the LOS receiver to the correct 50 kHz band is obtained from a satellite beacon radiating time information. If both the transmitter and receiver are aligned with the beacon clock, then the only uncertainty in time between the two stations is the ~45 msec corresponding to the difference in path delay between terminals at minimum and maximum range. The signal demodulator is used to acquire the beacon signal before communications begin. Since this acquisition is very rapid, and is required at infrequent intervals, the beacon frequency channel can also be shared with intermittent LOS users.

2. The fine tuning required for demodulator acquisition demands knowledge of time to a fraction of the 13 msec chip interval out of an initial uncertainty of 45 msec and knowledge of frequency to a fraction of the 75 Hz matched filter bandwidth out of an initial uncertainty of ~4 kHz for the worst case with a Mach 3 aircraft. To do this acquisition a preamble is transmitted in which the carrier frequency is hopped as during communication but with no message modulation. The frequency analyzer in the demodulator is used during the preamble to locate the signal and thereby generate information regarding the time and frequency offsets to tune the synthesizer. This acquisition should require from 2 to 5 seconds.

3. During communications the tuning of the synthesizer can drift due to oscillator instabilities and aircraft motion. Thus, during communications the time and frequency are tracked to measure the small changes in time and frequency thereby maintaining the receiver tuning.

TERMINAL COST

The modern high performance, high reliability LOS transceivers under development by the Air Force are expected to cost between $15K and $20K in quantity. Upgrading these radios to provide satellite communications compatibility should add another one to two thousand dollars.

To obtain narrow band satellite capability requires the addition of an input/output device at perhaps $3,000 and a narrow band modem at from $5K to $10K. Thus a narrow band terminal should cost between $24K and $35K. It requires exclusive frequency allocations.

On the other hand, we estimate the cost of the proposed compatible wide band modem to be from $15K to $20K, resulting in a terminal cost of from $34K to $45K. This cost is estimated from the fact that the modem parts cost appears to be about one-half that of fixed pattern TATS; the production price is scaled from that of the production TATS because the ratio of production price to parts cost is expected to be no greater.

CONCLUSION

The terminal proposed in this memorandum provides reliable, interference resistant satellite communications for mobile terminals without the need for exclusive frequency allocations. Its cost is about one-third more than that of a minimal terminal requiring exclusive frequency allocations.

We feel that the added performance and freedom from the allocations problem is well worth the small extra cost.

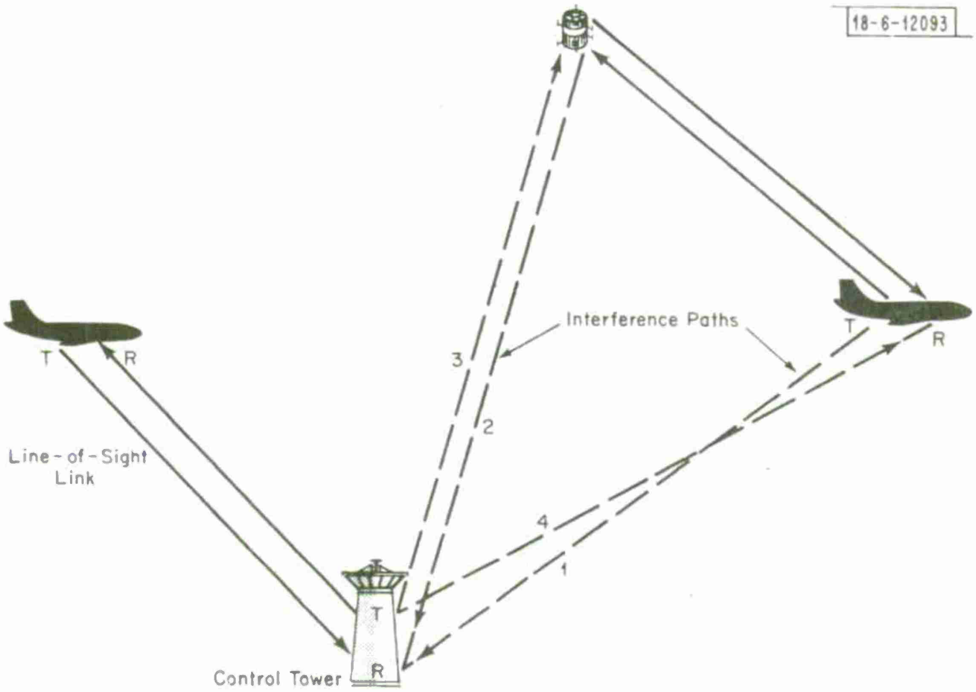

Fig. 1. Interference between satellite and L.O.S. users.

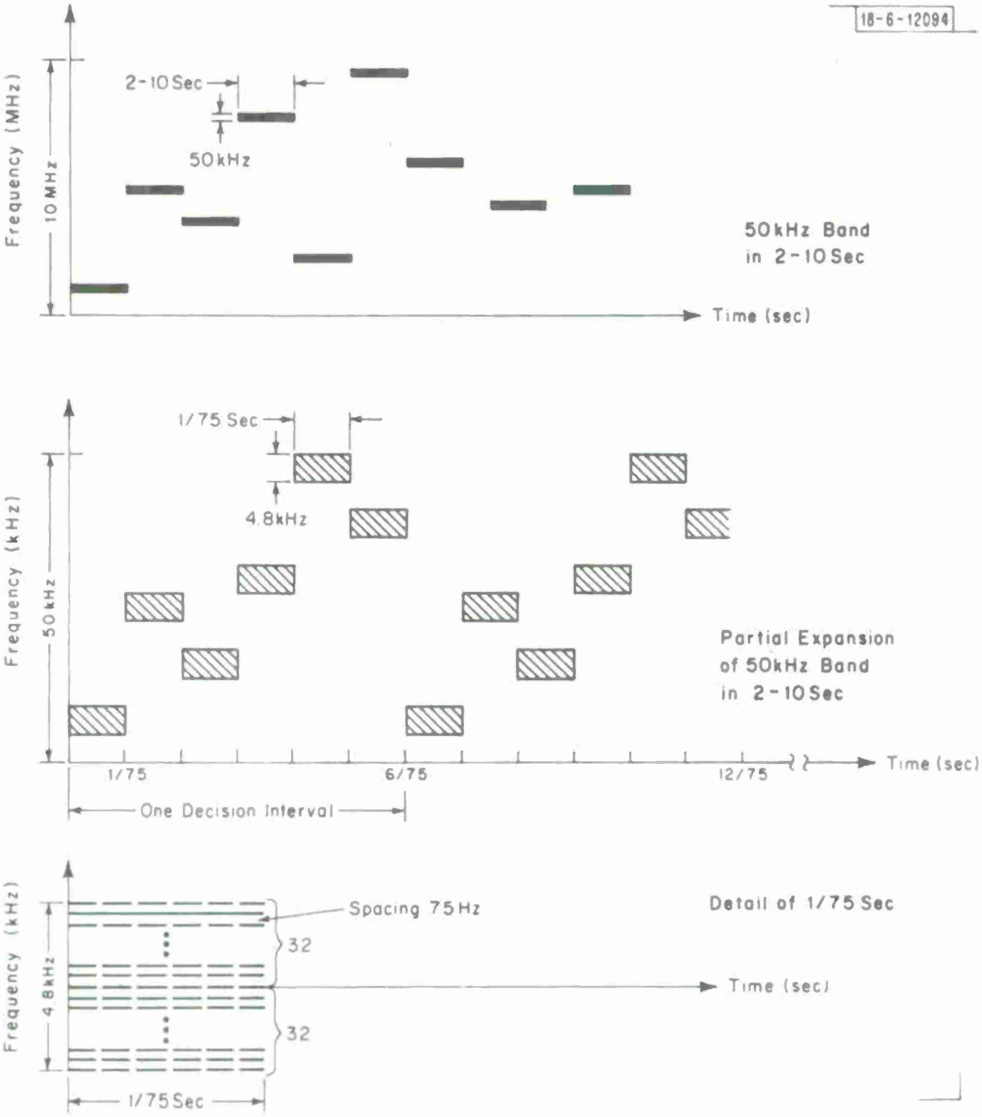

Fig. 2. Signal structure.

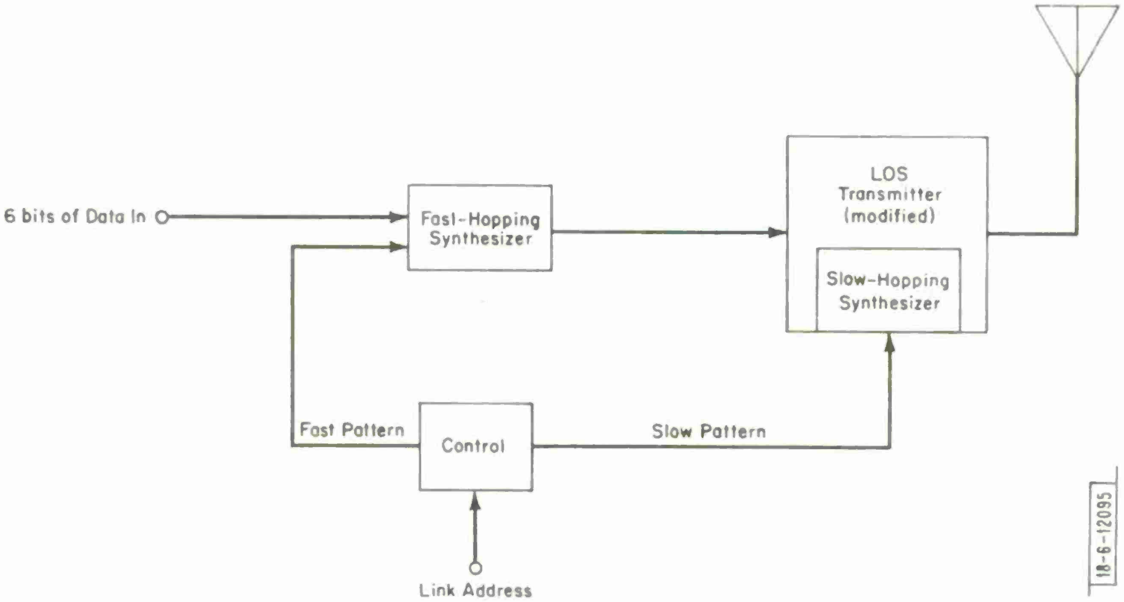

Fig. 3. Transmitter.

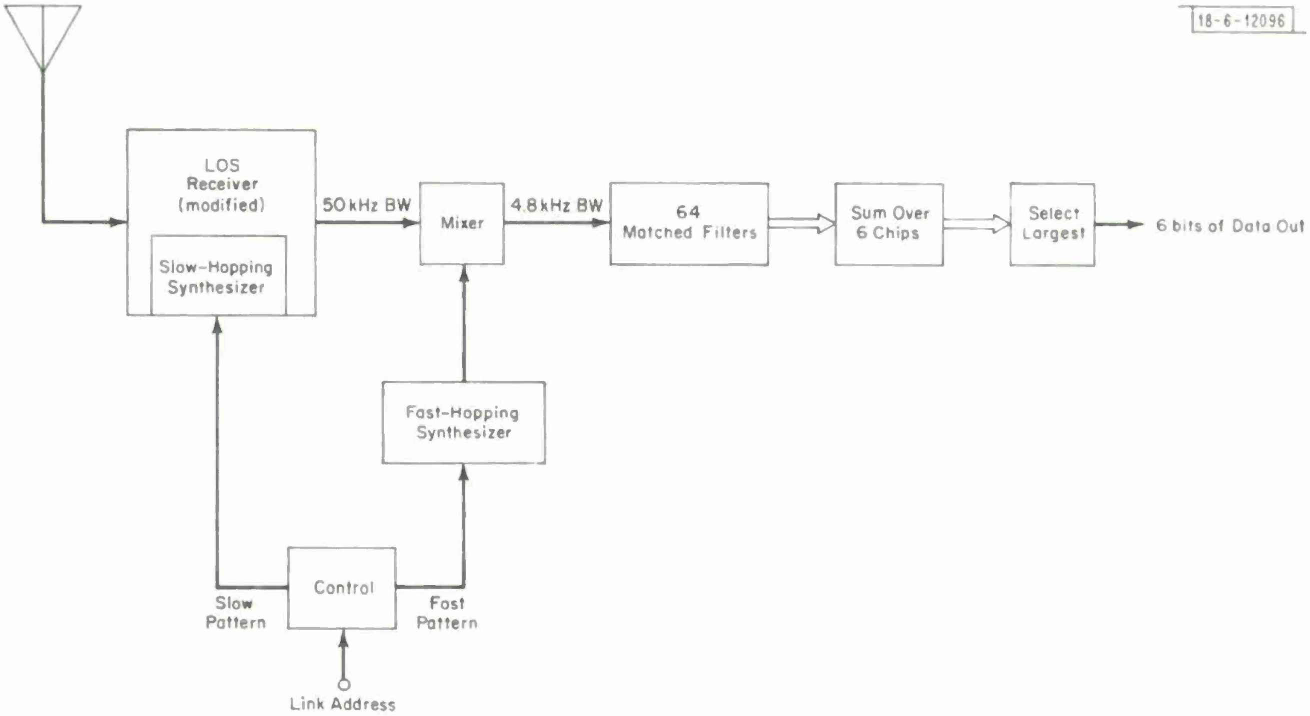

Fig. 4. Receiver.

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