PROBLEMS AND CHALLENGES IN SATELLITE COMMUNICATIONS
FREQUENCY REUSE - ANTENNAS AND COMPONENTS

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ABSTRACT

There are at present three frequency bands allocated for communication satellites in the USA. At the 4/6 GHz frequencies, 500 MHz bandwidth is available and several systems now or soon will operate in this band. These satellites are basically frequency translators with saturating amplifiers using 40 MHz wide channels. The capacity of these satellites range from 6000 to 14,000 analog voice circuits.

The second frequency bands for communication satellites are from 11.7-12.2 GHz down-link and 14.0-14.5 GHz up-link. Although this band is also 500 MHz wide, it is possible to achieve moderately high capacity systems through polarization and spatial frequency reuse. Up to 12 simultaneous, non-interfering beams can be formed from a moderate size satellite antenna. Thus there exists the potential of 6 GHz bandwidth per satellite. For several reasons it is not practical to use all of this bandwidth on a single satellite, today. However, we shall show that with multiple satellites, a system of 200-400 thousand digital voice circuits could evolve. For this reason it is worthwhile comparing the capabilities of a 12/14 GHz satellite system to the anticipated circuit requirements for time periods beginning around 1979.

A system recently studied consists of an eleven beam network which serves most of the 50 largest cities in the continental U.S. A switch is provided in the satellite so that all possible connections are available. The switch may be reconfigued to accommodate traffic demands which change with time. The capacity of the satellite is 36,864 two-way 64 kb/s circuits. With earth station antennas of only 7 meter diameter the outage for a typical link (New Jersey) due to rain is 0.01% or about 1 hr/year. In this talk we shall show that highly reliable service can be provided without the need for diversity earth stations.

The highest frequency bands allocated for communication satellites has 2.5 GHz bandwidth with the up-link nominally at 30 GHz and the downlink at 18 GHz can provide truely high capacity systems. It is estimated that as many as 50 million circuits could be accommodated in this band.

Looking into the future, we are considering systems containing perhaps 100 ground stations. It is apparent that a rather large number of hardware elements (receivers, filters, etc.) will be required in the satellite. There are at least two distinct ways of configuring the system. The first would be an extension of present domestic satellite practice of providing dedicated transponders on each beam-to-beam path. With 100 beams, it is obvious that a rather large number of comparatively narrowband transponders would be required. Alternatively, <u>all</u> of the multi-destination traffic at <u>each</u> ground station could be multiplexed onto a single carrier prior to transmission, permitting a significant reduction in the number of transponders, although each transponder would have increased bandwidth. Of course, there must now be means for demultiplexing and redirecting (switching) in the satellite. We shall illustrate how the traffic-carrying capacity of the satellite can be greatly increased due to the greater trunking efficiency of the latter system.

For each of the two system configurations mentioned, the total number of transponders required depends on certain details of the design ground rules. For example, we may be able to build transponders of arbitrary bandwidth, choosing the bandwidth of each to match the traffic load of each route or of each ground station, depending on the configuration chosen. In this case, for a 100-beam system, we would need $100(100-1)/2 = 4950$ total 2-way satellite transponders for a beam-to-beam system configuration. For a system using multiplexing at each ground station, clearly 100 2-way transponders, of properly chosen bandwidth would be needed. Obviously, the total system bandwidth requirements are the same in the two configurations; hence the former configuration requires nearly 50 times as many narrow-band transponders than the latter multiplexed system. It would also require a correspondingly larger number of IF filters, amplifiers, etc.

An alternative set of design rules would dictate building fixed-bandwidth transponders, and allocating as many contiguous (in frequency) transponders as necessary to serve each beam-to-beam route, or each multiplexed ground-station traffic load, depending again on the system configuration. In comparison with the previous design rules, more physical transponders are necessary in either system configuration, with an attendant increase, in either configuration, of the number of RF and IF components.

In one analysis of systems designed using the latter set of design rules, multiplexed systems were found to require on the order of several hundred 100-circuit transponders to serve a realistic 100-beam system. Without multiplexing at the ground stations, 10 to 100 times as many (narrower-band) transponders are required.

Obviously, there are several ways of implementing a switched multibeam satellite system. The intent here is to present a system in block diagram form which points out its salient features, so that the advantages will be apparent, yet the system concept is not lost in details. For convenience let us assume that the signals from all ground stations are digitally transmitted using the same size bundles dividing the total allotted spectrum by FDM. We assume that spatially separated ground stations may reuse the channels, thus using the entire allotted spectrum several times. Of course terminals with more traffic would require more bundles.

The left-hand side of Figure 1 shows a receiving array of M antennas where we might expect M to be in the range from 100 to 1,000. The incoming signals from the various ground stations are down converted to a convenient intermediate frequency. Next it is necessary to co-phase the incoming signals from the individual ground stations to form the proper beams. The signals co-phased at IF, are brought together to a common summing junction and then detected. The detected bit streams are shown entering the left-hand side of a switch.

For retransmission the bit streams modulate a carrier and then are split and combined with the conjugate phase of the carrier that was received on the left-hand side of Figure 1. These signals which now have proper phase information for form a beam to the appropriate ground station are added together in a combined with the signals destined for the other ground stations, amplified and transmitted.

Several questions concerning the satellite configuration will be considered as we proceed. Two options are available regarding phase conjugate retransmission. Since the transmitting and receiving bands are separated in frequency it is necessary to compensate the retransmission phase on the down link. This can be accomplished either by electronic phase multiplication or by using a separate scaled transmit antenna array; the better method has yet to be determined. We assumed that we are capable of reusing frequencies within the satellite band. To do this we must have proper side lobe discrimination to reject cochannel interference. Furthermore, if cochannel signals are to be used this also implies that the final amplifiers must be linear.

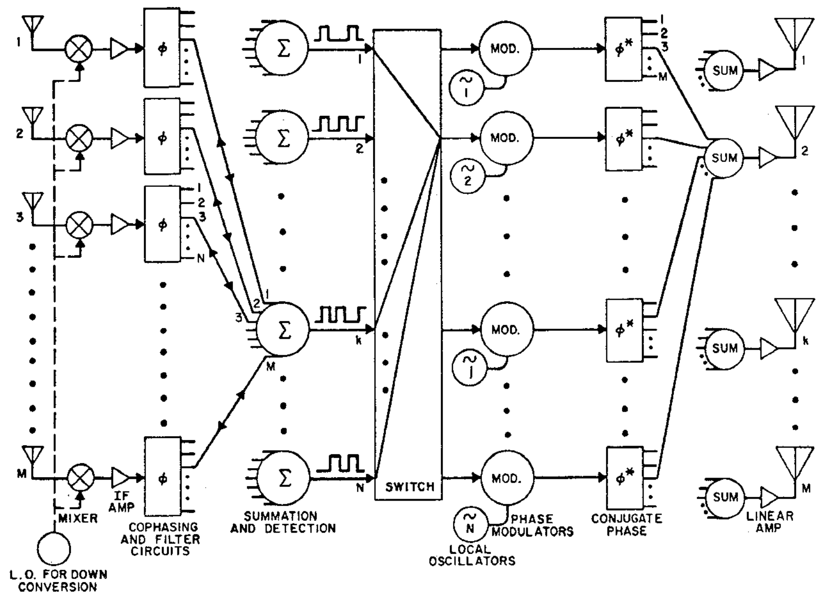

Fig. 1 Block diagram of a multibeam switched satellite.