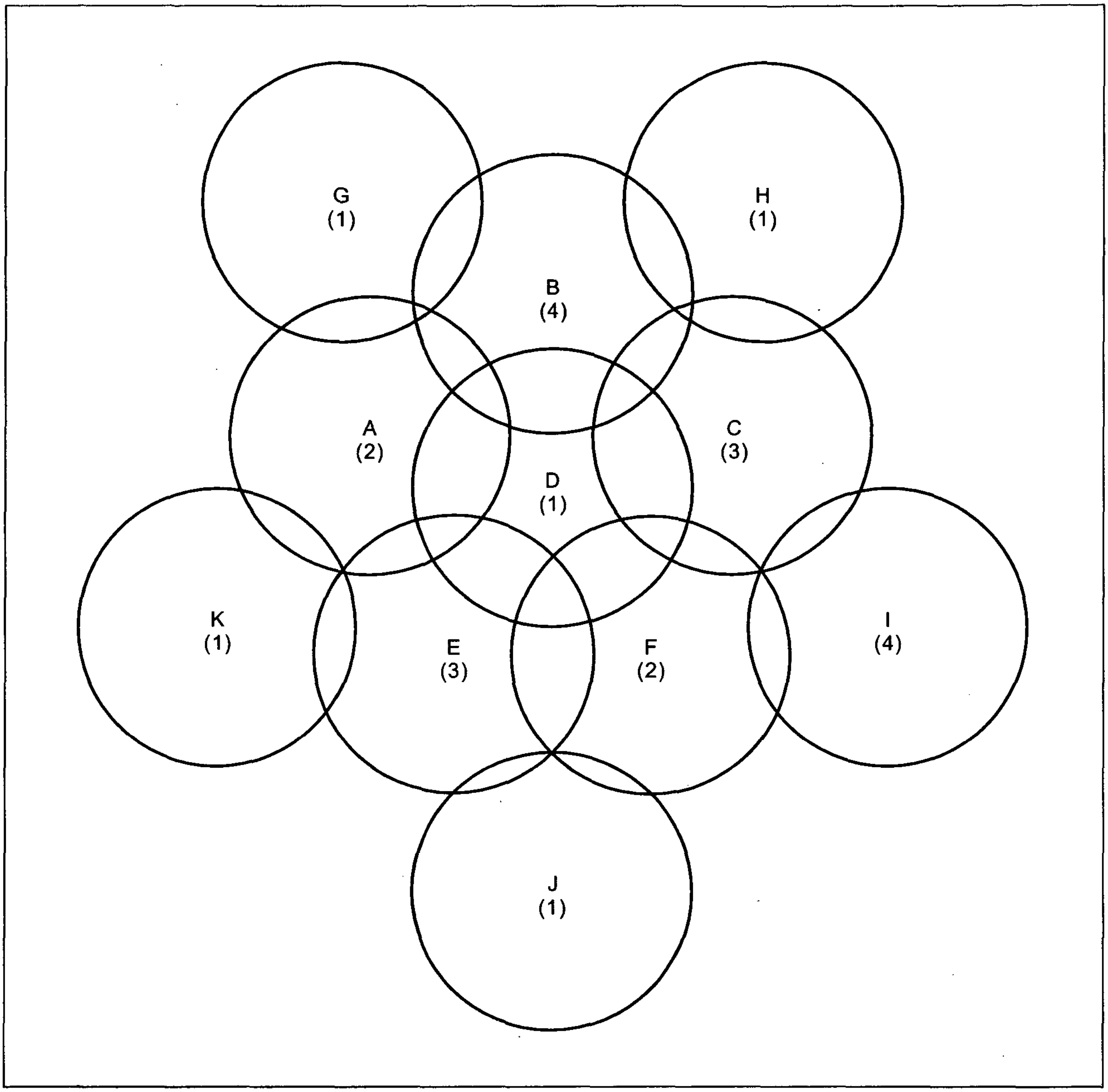

Figure 7-10. Possible interrogator identifier (II) code assignment (eleven ground stations)

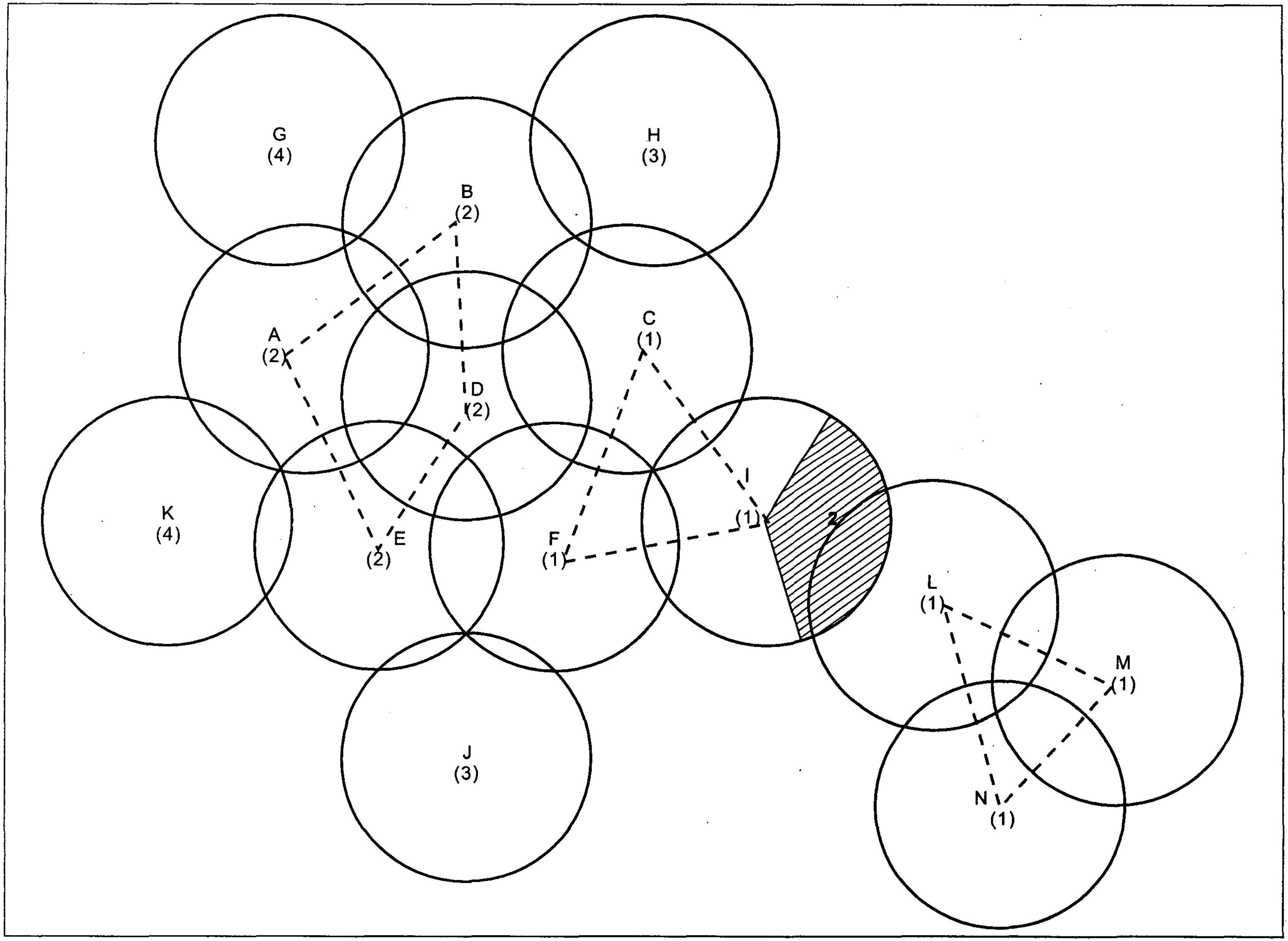

Figure 7-11. Possible interrogator identifier (II) code assignment with netted clusters of ground stations

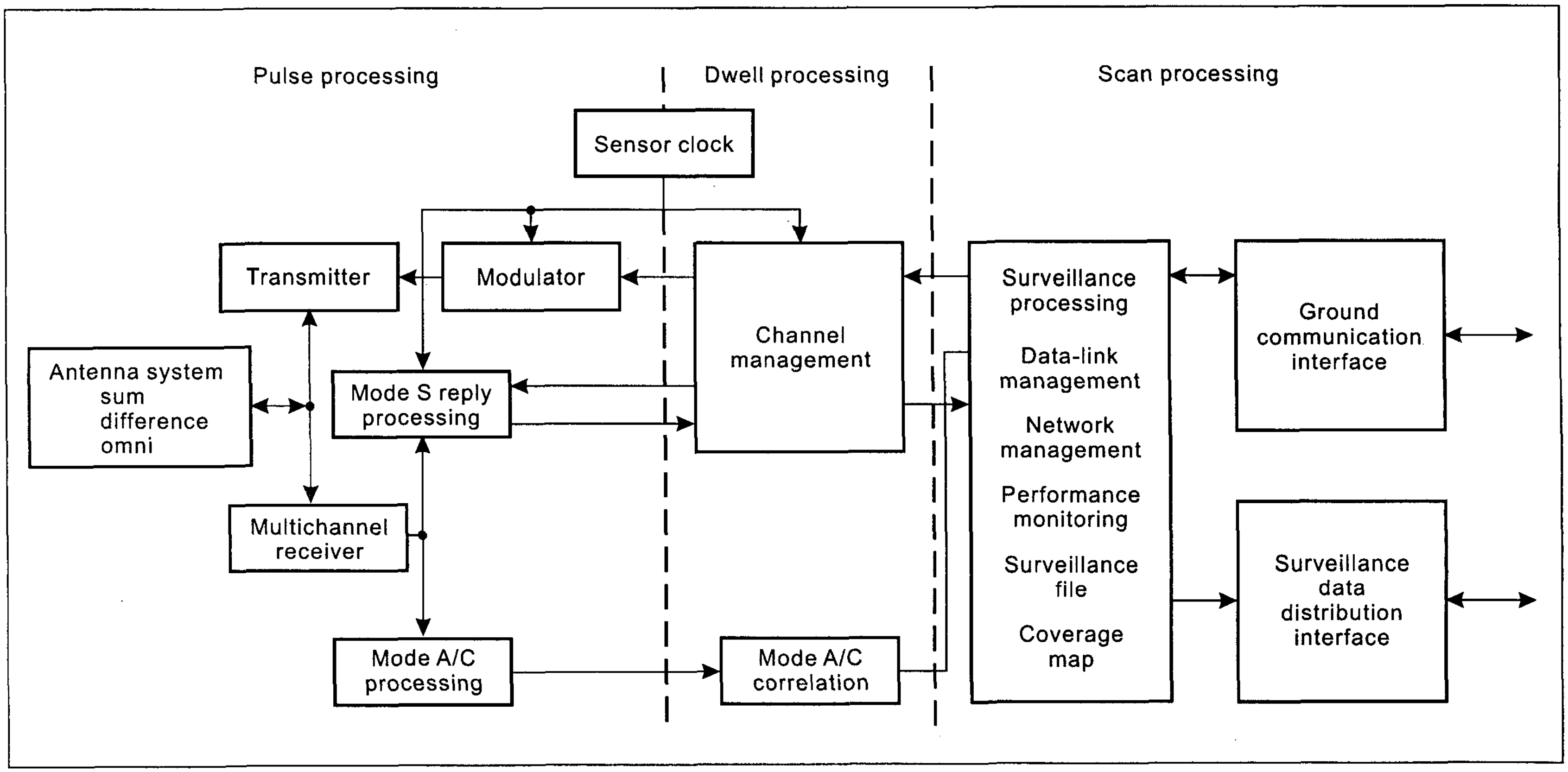

Figure 7-12. One example of a Mode S ground station functional block diagram

Chapter 8

INTERFERENCE CONSIDERATIONS

8.1 OVERVIEW

8.1.1 Mode S and Mode A/C SSR use the same interrogation and reply frequencies (1 030 MHz and 1 090 MHz). The availability of free time on both of these channels depends, on the one hand, on the number and distribution of aircraft in an airspace illuminated by the antennas of a group of ground stations and, on the other hand, on the interrogation (including the consequent suppression) rates and the number of replies from each aircraft. Since each ground station in the group interrogates independently of the others, it suffers from interference by replies generated in response to interrogations from other ground stations and also from transponders being occupied by other ground stations at the time access is being attempted.

8.1.2 Interference can result in a degradation of the system performance causing lost or wrong information. The reasons for this degradation are mainly transponder occupancy and RF signal distortion. Transponder occupancy is any mechanism that prevents valid signals arriving at the transponder from triggering the desired reply. RF signals on either uplink or downlink can be distorted by other overlapping RF signals which can make correct decoding of wanted signals impossible. The degree of degradation is a function of the channel loading.

8.1.3 Mode A/C transponders can give false information if a Mode C interrogation is converted to an apparent Mode A interrogation by an interference pulse from another interrogation falling in a position 8 microseconds or possibly 13 microseconds after the genuine P_1 pulse. Also, if an interference pulse falls a mode spacing before P_1, a reply will be generated at the wrong range and possibly in the wrong mode. Lost information occurs when the transponder is interrogated when it is either in suppression or in the process of replying to an interrogation from another ground station with overlapping cover.

8.1.4 When Mode S transponders are operating in a Mode A/C-only ground station environment the interference considerations are identical to those for Mode A/C transponders. The introduction of Mode S ground stations into such an environment will, however, result in different interference mechanisms, the effect of which will depend on many factors including the number of Mode S and Mode A/C transponders and the particular Mode S protocol in use.

8.1.5 The interference phenomena are different for uplink and downlink. In an environment where Mode A/C and Mode S equipment are used in the same airspace, the effect of interference is different for each system. For example a Mode A/C transponder is suppressed by a Mode S interrogation while a Mode S transponder will process the interrogations and reply if it is correctly addressed.

8.1.6 SSR system-generated interference can be minimized by a) using the lowest transmitter power level possible, consistent with desired performance and b) ensuring that interrogation rates are as low as possible and are not synchronous with any ground station having overlapping cover. PRF stagger can also be used, thus ensuring that synchronous interference does not take place.

8.1.7 The transponder cannot process incoming RF signals for interrogation acceptance under the following conditions:

a) it is suppressed on its internal aircraft suppression bus due to RF transmission from other avionics equipment;

b) it is in a transaction cycle; or

c) it cannot decode Mode A/C signals when a P_1-P_2 suppression pair has been accepted, until the suppression period is over.

8.1.8 An important consideration in reducing channel activity is assigning the minimum number of interrogators to a region of airspace, consistent with operational requirements. The combination of II and SI codes makes it possible to uniquely identify 78 different interrogators or clusters. This unique identity capacity has been provided to ease the assignment of interrogator codes, especially for the case of mobile interrogators. It must not be allowed to become a reason for over assignment of interrogators in a region of airspace, since this will lower the performance to all users.

8.2 TRANSPONDER OCCUPANCY

GENERAL

8.2.1 A transponder is occupied from the time it detects an incoming signal that causes some action to be initiated, e.g. either a valid interrogation or suppression pair, to the time that it is capable of replying to another interrogation (including turnaround delay, reply time and dead time). For valid interrogations generated by one SSR or Mode S ground station, the occupancy depends on whether:

a) it is in the cover of the main beam only or in the side-lobe cover; or

b) it is an interrogation that does or does not elicit a reply.

IN THE MAIN BEAM OF A MODE S GROUND STATION

8.2.2 Assuming the ground station is also interrogating on Mode A/C, a Mode A/C transponder will be occupied in the normal way to these interrogations but in addition it will be suppressed for every Mode S interrogation made while it is in the beam.

Note.— Mode A/C transponders treat intermode interrogations as conventional Mode A/C interrogations.

8.2.3 A Mode S transponder will be occupied by all Mode S interrogations specifically addressed to it. This includes Mode S-only all-call and broadcast interrogations. It will also be occupied by intermode interrogations with a long P_4. It is possible to minimize the transponder occupancy by both types of all-call interrogation by using the lockout protocol.

8.2.4 A Mode S transponder will be occupied by the receipt of main-beam Mode S interrogations addressed to another aircraft. The transponder must fully decode the interrogation to determine the address contained in the message block. Once the transponder determines that the interrogation is intended for another transponder, it will resume normal operation. This activity will nominally require 45 microseconds.

IN THE SIDE LOBES OF A MODE S GROUND STATION

8.2.5 A Mode S transponder will only be occupied by a Mode S interrogation specifically addressed to it. This should not normally happen in the side lobes. The transponder will however be occupied to Mode A/C for the suppression period after the receipt of every (P_1-P_2) pair. However, during and after the receipt of a Mode S side lobe interrogation, the Mode S transponder will not be able to detect valid interrogations which are below the current threshold up to the time of recovery to full sensitivity.

8.2.6 A Mode A/C transponder will be occupied by the normal suppression for Mode A/C and intermode interrogations.

8.2.7 It is important to note that a Mode A/C transponder will be suppressed by every Mode S interrogation, including broadcast and Mode S-only all-call interrogations, made by that ground station.

8.2.8 If selectively addressed Mode S interrogations are transmitted without an accompanying P_5 suppression pulse, all transponders receiving the interrogation will be occupied until the interrogation has been fully decoded. If the interrogation is accompanied by a P_5 pulse, the transponder is only prevented from decoding other interrogations until the sync phase reversal recognition fails, followed by the receiver recovery time.

SELECTIVE MODE S TRANSPONDER OCCUPANCY

8.2.9 The Mode S protocols provide the facility to lock out the transponder to all types of all-call interrogations requiring a Mode S reply. This can be regarded as permanent occupation of the transponder to that type of interrogation and great care must be exercised to ensure that the use of these protocols does not prevent other ground stations with a need to acquire the transponder through all-call interrogations from doing so.

TABLE OF TRANSPONDER OCCUPANCY FOR DIFFERENT INTERROGATIONS

8.2.10 The total occupancy is made up of several nominal times as listed in Table 8-1. The term "transaction cycle", defined in Annex 10, Volume IV, Chapter 3, 3.1.2.4 is used for Mode A/C transponders in the same manner as for Mode S transponders. (Note that the time for an additional SPI in a Mode A/C reply is not included.)

Note.— The total processing times for all interrogation types are listed in Table 8-2. The items in parentheses are references to the rows of Table 8-1.

8.3 CHANNEL LOADING

GENERAL

8.3.1 The channel loading is different on the uplink and on the downlink. For conventional SSR systems (Mode A/C) one interrogation is replied to by all transponders receiving that interrogation. Thus, the downlink loading is sometimes considerably higher than on the uplink.

8.3.2 When the selective interrogations of a Mode S ground station are used each selective interrogation normally triggers only one reply. This leads to a more balanced channel loading in terms of number of transmissions. Since the uplink transmission bit rate of 4 MHz is four times greater than on the downlink the total channel occupancy time on the uplink is also only 1/4 of the downlink loading for equivalent transactions.

UPLINK LOADING

8.3.3 The uplink channel loading should be measured or defined at the antenna of any aircraft in terms of interrogations per time unit or time occupancy. The loading is dependent on the location of an aircraft, i.e. the distance to a ground station and the flight level, which determines how many ground stations are illuminating it.

8.3.4 Inside the side lobes of a ground station antenna, an aircraft receives continuously all interrogations from the ground station. Since this area is normally controlled by an omni suppression technique, suppression pulses will also be received.

8.3.5 Outside the side lobes the loading is due to the limited effective beamwidth of a rotating antenna dependent on the time when the beam sweeps through an aircraft.

8.3.6 Considering an aircraft being in the effective beam of a Mode S ground station antenna, the channel loading originating from this ground station is a function of the number of aircraft being selectively interrogated and of the degree of activity for surveillance and/or data link purposes. The channel loading is a function of the azimuth but can also vary with time.

8.3.7 The overall loading is dependent on the total number of ground stations interrogating the aircraft, measured during an interval of the order of one minute. This loading value represents a mean value, whereas during such an interval, peak values can be measured that are considerably higher than the mean value.

8.3.8 Since the channel loading is heavily dependent on the scenario, i.e. the number of ground stations, type and number of interrogations, number of aircraft and their type of equipment, etc., only some examples for typical scenarios can be given.

8.3.9 The replacement of a conventional ground station, using sliding window techniques, with a Mode S ground station reduces the Mode A/C interrogation rate due to the use of the monopulse technique. In this case, the all-call interrogation rate is typically between 100 and 150 per second. Assuming an effective beamwidth of 3.6 degrees and an antenna rotation time of 5 seconds, an aircraft located in the main lobe would receive between 5 and 8 all-call interrogations during each scan. Inside the side lobes the aircraft would receive all interrogations, i.e. 100 to 150 per second. When intermode interrogations can be used to acquire Mode S transponders, the same interrogation rate applies.

8.3.10 A Mode S-equipped aircraft may be selectively interrogated during a beam dwell time of 50 milliseconds with up to 15 surveillance or Comm-A interrogations. A 16-segment uplink ELM may be transferred during this time, whereby replies required for ELM delivery reduce the number of the former mentioned interrogations. These figures are derived from the minimum reply rates for Mode S transponders.

8.3.11 From highly loaded scenarios it is known that up to 15 aircraft can be simultaneously within the beam, while typical peak values are about 5 to 8 aircraft. Assuming all aircraft to be equipped with Mode S transponders and high data link activity, the number of Mode S interrogations can be in the order of 100 during a beam dwell which would produce (in the given example) a peak interrogation rate of 2 000 per second. The maximum repetition rate for selective interrogations is limited to 2 400 per second averaged over a 40 millisecond interval.

8.3.12 For the delivery of an uplink ELM, the interrogation segments are normally transferred closely spaced. Therefore, they represent a higher potential for interference compared with surveillance or Comm-A interrogations.

DOWNLINK LOADING

8.3.13 The downlink loading should be measured or defined at the antenna of a ground station. This loading is a function of the number of aircraft within coverage and the number of interrogations from other ground stations interrogating the same aircraft in the same time period.

8.3.14 In the case of surveillance and standard length message transactions, the downlink loading corresponds to the uplink loading since a reply can only be triggered by an interrogation. It should be noted, however, that each Mode S transponder also transmits a squitter reply once each second.

8.3.15 As in a pure Mode A/C environment, all replies triggered by other ground stations are named fruit, so that the Mode A/C and Mode S fruit rate corresponds to the degree of uplink loading in the environment of the ground station where the fruit rate is determined.

8.4 SSR GARBLING

8.4.1 SSR replies from transponders can be corrupted by other signals arriving at the same time at the interrogator receivers. Interference that leads to the corruption of the reply is referred to as garble. There are two types of garble:

a) *Asynchronous garble.* The SSR reply is corrupted by a random signal that is not synchronized with the SSR interrogations.

b) *Synchronous garble.* The SSR reply is corrupted by other replies to the same interrogator.

8.4.2 Asynchronous garbling rarely causes corruption of the complete radar plot data for an aircraft. This is because the SSR system transmits several interrogations to each aircraft as the beam sweeps past. It is unlikely that random interference will corrupt all of the replies in the beam. The radar performs an averaging function of the replies that correlates across the beam reducing the impact of any random errors. Also, the radar typically performs scan to scan or track correlation that may have further error correcting functions that depend on the history of the aircraft track in the system. The most common source of signals leading to asynchronous garble is the replies from aircraft responding to other interrogators and airborne collision avoidance systems (ACAS). This is why it is important to operate neighbouring interrogators with different pulse repetition frequencies (PRF) and to operate random PRF stagger functions (in order to ensure that the interrogators remain unsynchronized).

8.4.3 Synchronous garbling occurs when aircraft close to each other in slant range respond to the same interrogation. Depending on the range difference between the aircraft, the reply pulses may overlap or interleave with each other. A standard SSR Mode A or C reply is approximately 1.7 nautical miles long; therefore, aircraft within this range of each other (slant range difference), at similar azimuths (i.e. within the antenna beam width), have a chance of the reply pulses overlapping each other. Because the replies from all aircraft are synchronized to the interrogator, multiple replies across the beam may be corrupted which may cause the reply averaging function of the radar to produce an erroneous result. If the garble situation persists from scan to scan, then the radar track history error correcting functions may also be corrupted. The following may result:

a) incorrect Mode A code for the aircraft;

b) incorrect Mode C (flight level) for the aircraft;

c) code swaps, where the wrong Mode A and/or Mode C data are associated with the aircraft;

d) phantom aircraft, where the overlapping reply pulses form a new aircraft (between the real aircraft) where one does not exist.

8.4.4 Synchronous garbling can occur when aircraft are at similar azimuths and at similar slant ranges, even where there may be large altitude separation, and can persist for several scans. Situations where synchronous garbling can occur include:

a) aircraft stacks where aircraft in the stack are moving around directly above and below each other;

b) groups of gliders riding the same thermal and flying small circuits above and below each other;

c) aircraft flying in the same airway at similar range and speed;

d) aircraft tracks crossing at a coincident range and azimuth;

e) helicopters converging to attend or provide television coverage of events such as concerts, horse racing and motor racing;

f) recreational flying events where multiple aircraft converge.

8.4.5 It is recommended that, for ATC operations based on SSR plot data, an operational objective should be to avoid synchronous garble situations persisting by carefully directing traffic to avoid loss of range and azimuth separation, even where altitude separation is being maintained.

8.4.6 Mode S radar systems employ techniques to avoid synchronous garble. During all-call acquisition, stochastic reply functions are employed to de-garble all-call replies where aircraft are in close proximity to each other. During roll-call surveillance, each aircraft is individually interrogated, thus avoiding synchronous garble.

8.5 RF INTERFERENCE FROM OTHER SYSTEMS

8.5.1 The SSR system requires a 3 dB receiver bandwidth of approximately 8 MHz centred on 1 030 and 1 090 MHz for the airborne transponder and ground SSR receiver respectively. This bandwidth is sufficient to permit significant co-channel interference from transmitters operating on adjacent frequencies. This interference can be minimized by ensuring adequate frequency or spacial separation between the interfering transmitters and the SSR receivers. Two air traffic service (ATS) systems, DME and primary radar, can be the cause of interference. In the case of DME it is advisable to take care in using the DME channels adjacent to the SSR frequencies as transmission on these channels can cause interference to SSR. Some primary radar transmitters make use of two frequencies that if separated by 60 MHz can cause intermodulation products with consequent problems to collocated SSR systems.

8.5.2 Any incoming signal may cause the transponder to miss a valid interrogation. The duration of the interference depends on the signal source, the signal duration on the 1 030 MHz channel and the signal amplitude at the transponder antenna followed by any recovery from desensitization.

Table 8-1. Relevant times for transponder occupancy

		Mode A/C	*Intermode*	*Mode S short*	*Mode S long*
a)	**interrogation**				
a1)	signal duration	8.8 μs 21.8 μs	10.8, 11.6 μs 23.8, 24.6 μs	19.75 μs	33.7μs5 μs
a2)	reference 2)	8 μs 21 μs	11.6 μs 24.6 μs	4.75 μs	4.75 μs
b)	**transaction events** 1)				
b1)	reply delay	3 μs	128 μs	128 μs	128 μs
b2)	reply duration	20.75 μs	64 μs	64 μs	120 μs
b3)	transaction cycle: reply	23.75 μs	192 μs	192 μs	248 μs
b4)	transaction cycle: no reply			15 μs	29 μs
c)	**dead time**	up to 125 μs	up to 125 μs	up to 125 μs	up to 125 μs
d)	**suppression**				
d1)	signal duration	2.8 μs	—	19.75 μs	33.75 μs
d2)	reference 2)	2 μs	—	4.75 μs	4.75 μs
d3)	suppression interval	35 μs	—	—	—
e)	**recovery**				
e1)	single pulse, interference	up to 15 μs 3)	up to 15 μs 3)	up to 15 μs 3)	up to 15 μs 3)
e2)	interrogation not eliciting a reply	—	—	45 μs	45 μs

Notes.—

1) Starting at reference.

2) Timespan from the beginning of the signal.

3) Depending on the signal amplitude beginning at the trailing edge of the signal (last pulse).

Table 8-2. Table of transponder processing times

Received signals	*Total transponder processing time* [1) 2)]	
	Mode A/C transponder	*Mode S transponder*
P_1P_3, Mode A Mode C	156.75 µs (a2+b3+c) 169.75 µs (a2+b3+c)	156.75 µs (a2+b3+c) 169.75 µs (a2+b3+c)
P_1 P_3P_4 short, Mode A Mode C	156.75 µs (a2+b3+c) 169.75 µs (a2+b3+c)	26.6 µs (a2+e1) 39.6 µs (a2+e1)
P_1 P_3P_4 long, Mode A Mode C	156.75 µs (a2+b3+c) 169.75 µs (a2+b3+c)	328.6 µs (a2+b3+c) 341.6 µs (a2+b3+c)
P_1P_2	37 µs (d2+d3)	47 µs (d2+d3) for Mode A/C 4.75 µs (a2) for Mode S
$P_1P_2P_5P_6$	37 µs (d2+d3)	4.75 µs (a2)[3)]
$P_1P_2P_6$ correctly addressed, short reply long reply	37 µs (d2+d3)	321.75 µs (a2+b3+c) 377.75 µs (a2+b3+c)
$P_1P_2P_6$ not addressed	37 µs (d2+d3)	49.75 µs (a2+e2)
no received signal		
Squitter, short long	—	189 µs (b2+c) 245 µs (b2+c)

Notes.—

1) *Additional effects may occur due to reply rate limiting.*

2) *The maximum value of dead time (125 µs) is used in the processing times values calculated in the table. Typical values are significantly lower.*

3) *In this case the incoming RF signal extends beyond this time and other incoming signals will only be decoded if they are sufficiently above the receiver threshold set by the original signal.*

Chapter 9

THE MODE S SUBNETWORK OF THE ATN

Note.— This chapter contains references to SARPs which are in Annex 10, Volume III, Part I dedicated to digital data communications.

9.1 CONSIDERATIONS CONCERNING DIGITAL DATA INTERCHANGE

INTERNETWORK ARCHITECTURE

9.1.1 An internetwork data communication architecture (i.e. an architecture composed of multiple interoperating networks) offers the greatest flexibility in design, management and control of each independent subnetwork and allows each subnetwork to be optimized for use in its own environment. The alternative (i.e. one unified subnetwork encompassing all aircraft and ground processing) would impose an unnecessarily high degree of standardization and present formidable management problems. This would be especially undesirable in an environment where various avionics application processors need to exchange data with various ground-based application processors, all operated and controlled by different authorities and organizations.

9.1.2 The aeronautical data communication logical connectivity illustrated in Figure 9-1 may be described as an internetwork architecture.

9.1.3 Data transfer through an aeronautical internetwork environment is supported by three types of data communication subnetworks:

a) avionics subnetworks;

b) ground subnetworks; and

c) air-ground subnetworks.

9.1.4 The transfer of data between two end-systems (i.e. application processors) of the aeronautical data communication system is accomplished through the interconnection of these subnetworks in a manner providing a continuous path between the respective end-systems.

AVIONICS SUBNETWORKS

9.1.5 Modern aircraft will, in general, incorporate one or more internal subnetworks which interconnect the various processes required for the operation of flight systems. These are referred to as avionics subnetworks. In an aircraft equipped for aeronautical data communication, these subnetworks are used to interconnect the aircraft data communication processors (such as the Mode S airborne data link processor (ADLP)) with aircraft application processors (such as data display processors, data entry processors and flight management computers).

9.1.6 In the simplest (i.e. single air-ground subnetwork) case, an aircraft application processor may be connected directly to a dedicated data communication processor (stand-alone operation). Where internetwork operations are desired, each aircraft application processor may have access to one or more data communication processors and thus to their respective air-ground subnetworks.

GROUND SUBNETWORKS

9.1.7 Contemporary ground-based data processing facilities require a similar level of connectivity among the various processors local to that facility. A ground subnetwork provides the required connectivity within such a facility, often in the form of a local area network (LAN). The ground subnetworks also provide interconnection of ground application processors with ground data communication processors (such as the Mode S ground data link processor (GDLP)), in order to access the aircraft-resident end-systems.