INTRODUCTION TO SECONDARY RADAR

BASIC PRINCIPLES

1. Secondary Radar (SR) is a radio location system which, basically, measures time elapsed between a transmitted and a received radio signal and hence can determine the range and bearing of a target. In contrast with normal radar techniques, which use the echo reflected from the target, secondary radar uses an active device in the target to transmit a signal on receipt of a signal from the ground transmitter. This two-way interchange of transmitted signals may be compared to a target being questioned by a ground station and responding by transmitting a reply. This has led to the ground transmitter being known as the 'interrogator' and the active device in the target, the 'transponder' (transmitter-responder).

EVOLUTION OF SR EQUIPMENT

2. The first operational use of SR systems was in 1941-2 when Great Britain produced the IFF (Identification, Friend or Foe) Mk II system, this utilised a transponder reply directly to the primary radar 'interrogation'. Towards the end of World War II the Allies had developed IFF Mk V, this embodied two main advances: a separate frequency was employed for interrogation and reply, and the pulse width within the reply could be varied to permit a Morse coded information content. At the end of World War II research was undertaken to develop a high security IFF system, but before such a system reached production the need became apparent for an improved 'conventional system' as higher aircraft speeds were making the rate of information transfer from primary radar and IFF Mk V too slow for operational or Air Traffic Control use. The new system became known as IFF Mk X (as it was not certain what mark number would be allocated to the system, official papers referred to it as IFF Mkx, 'x' being an unknown; since mark numbers had traditionally been Roman numerals, x soon became corrupted to X, and so ......!). IFF MkX was later expanded to include a selective identification feature (SIF) in which replies could be coded at the user's option. The version IFF Mk10 (SIF) was subsequently given an increased number of coding options and became IFF Mk10A, now the current SR system in service.

ADVANTAGES OF SR SYSTEMS

3. Before discussing the advantages of SR systems it is useful to consider the disadvantages of primary radar. Primary radar depends on the reflection of radio signals. To survive the two-way path the emitted signals must be transmitted with relatively high power and so require large aerials. Further disadvantages of primary radar are:

a. The display is affected by ground and weather clutter

b. Returns are affected by aircraft size and attitude

c. Identification of aircraft requires manoeuvres

d. There is no instantaneous means of indicating distress

e. All aircraft returns look similar on the radar display

4. The main advantage of primary radar is that it is self contained and requires no co-operation from the aircraft.

5. The present day SR system has the Interrogator transmitting pulses on 1030MHz and the aircraft Transponder replying on 1090Mhz. The replies received by the Interrogator are displayed either on the radar display or as a numerical read-out. The aircraft on accepting the ground signal sends back a new signal as against reflecting the original signal and so to achieve similar range to primary radar considerably less ground transmitting power is required; aircraft are normally fitted with top and bottom aerials so the reply is independant of the aircraft size and attitude. Transponder replies can be varied in content and with only transponded replies displayed no ground clutter or precipitation will be represented on PPIs.

6. Thus compared to primary radar, the advantages of secondary radar can be summarised as follows:

a. Increased range for lesser transmitted power and smaller aerial

b. No clutter from weather or permanent echoes on the radar display

c. Returns independant of aircraft size and attitude

d. Positive identification without aircraft manoeuvres

e. Positive and instantaneous means of indicating emergencies

f. Air to ground information link

DISADVANTAGES OF SR SYSTEMS

7. SR systems disadvantages are split between technical problems and ATC considerations; most of the technical system limitations stem from the fact that SR is in such wide use today and many of these problems are now being overcome. The main disadvantages are:

a. Aircraft must carry specialised equipment

b. All aircraft must be equipped before a full separation service can be given

c. A high rate of serviceability or duplication of airborne equipment is required

d. Technical problem characteristics may degrade/render inaccurate the presentation of SR information, for example:

(1) Fruiting - reception of transponder replies by ground stations other than the interrogating one may result that echoes at false ranges and bearings can be displayed.

(2) Garbling - if a second aircraft is sufficiently close to the first to be interrogated, its reply may overlap that of the first aircraft and the resulting pulse train will consist of two corrupted messages which will be impossible to decode accurately. - Red lights

(3) Sidelobe signals - the interrogator receiver receiving signals from outside the main lobe and the system displaying them as targets at fictitious bearings.

(4) Saturation - if the rate of incoming interrogations exceeds a given value, then, in order to protect the transponder, its sensitivity is reduced. In this configuration, the interrogation of remote stations will not be received.

(5) Transponder Suppression - transponders are unable to reply to an interrogation having just replied to a previous one, for a period which may be anything up to 125 micro secs. It is therefore possible that interrogation will occur which will be ignored by the transponder.

8. Fig 1 shows in simplified form the main components of a SR system.

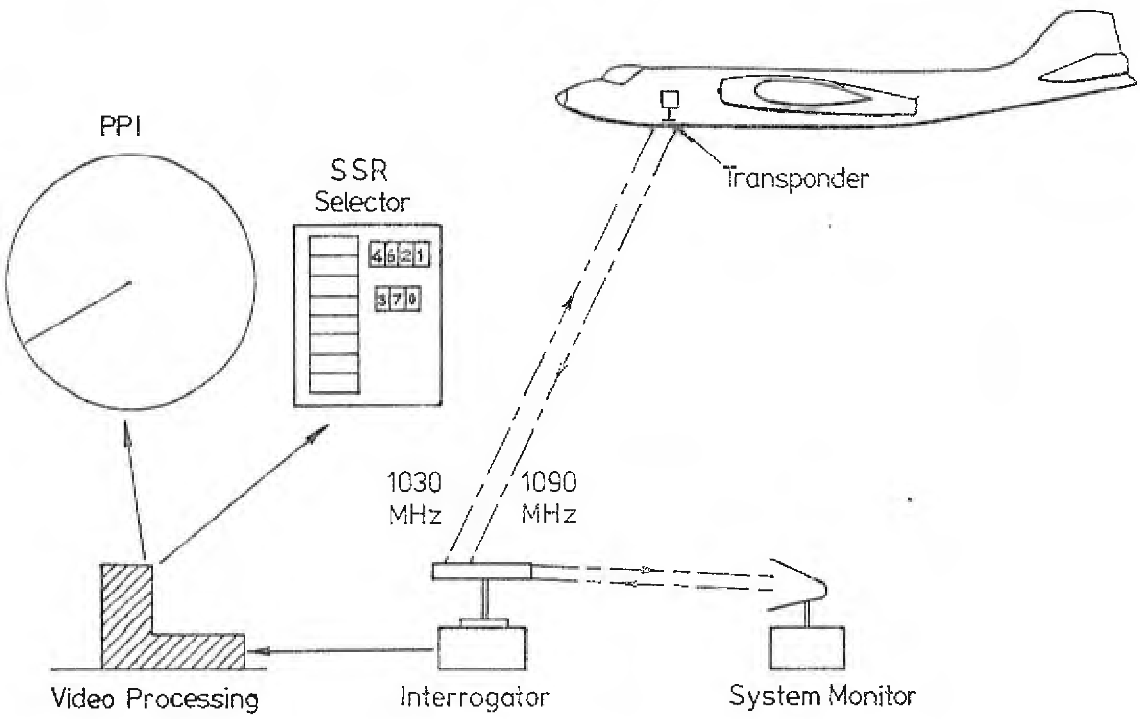


Fig 1

NATURE OF SR SIGNALS

9. The main feature of SR is that the aircraft responds to an interrogation from a ground station. In a military context, SR offers the most practical means of achieving the necessary identification of friendly aircraft; this use is known as 'Identification - Friend from Foe' or 'IFF'. There are also further uses of SR in the purely military context, but not the subject of this Note.

10. Since a reply is sent from the aircraft to the ground station, it is possible to use the reply to convey information about the specific aircraft making the reply; this information is in practice used to inform the ATC units of various data regarding the aircraft. In the ATC context, SR is often known as Secondary Surveillance Radar (SSR).

11. In both the above cases, information is passed from air to ground. The type of information passed depends on the format of the interrogation (interrogation MODE) from the ground station. The interrogation is transmitted in the form of a pulse train as shown in Fig 2 and the MODES are differentiated by the spacing of the interrogation pulses. This spacing between the Mode Pulses will be 3, 5, 8 or 21 micro secs. Normally, only 2 interrogation Modes may be transmitted at once; typically Mode 3/A and Mode C (see Fig 4). The transponder in the target transmits a reply for any Mode which has been selected to be activated; typically a pilot would select Mode 3/A with Mode C, but a fighter may also select Modes 1 and 2. The reply to the interrogation takes the form of a train of pulses as at Fig 3. The information contained within the reply is known as a CODE. The ATC information coded in this way is the 4-figure code and altimeter information. Each figure of the 4-figure code may have a value from 0 to 7; this gives a potential total number of codes of 4096 (8^4). Coded altimeter information is transmitted in response to Mode C interrogation; the information is based on the Standard Pressure and is not adjustable in flight and it is displayed to the nearest 100 ft as a 3-figure FL. Modes 1 and 2 are used for other Military purposes (see Fig 4).

MODES

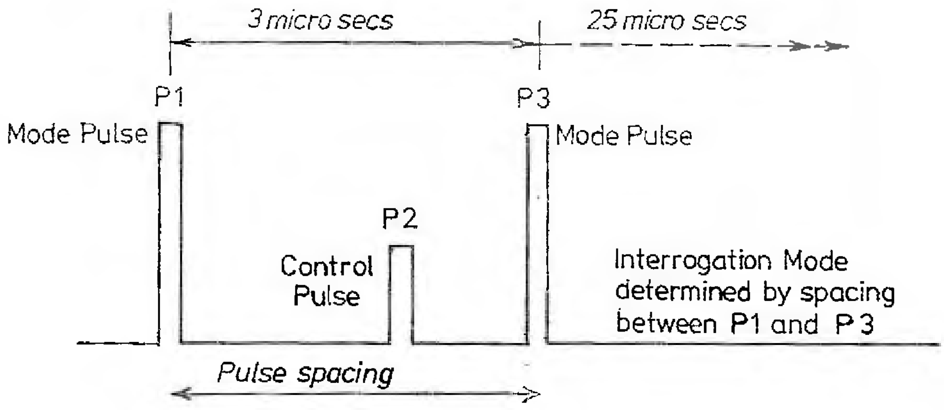


Fig 2

CODES

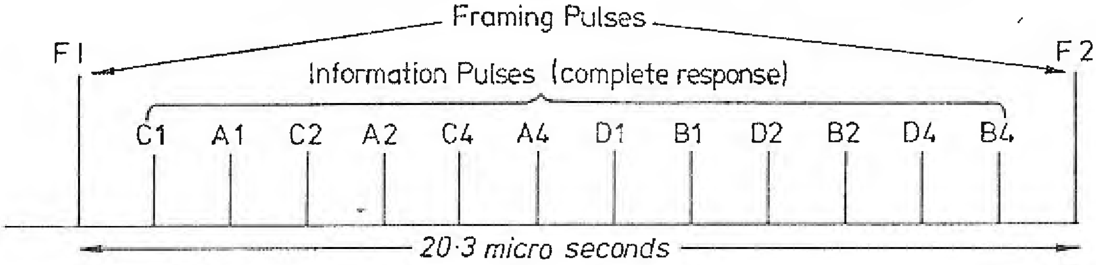


Fig 3

MODE	INTERROGATION PULSE SPACING	REPLY INFORMATION
1	3 micro secs	Military parentage code. Not ATC.
2	5 micro secs	Military individual code. Not ATC.
3/A	8 micro secs	Joint Military/Civil information. Military and ATC.
B		Not used in Europe.
C	21 micro secs	Coded height information.

Fig 4

12. The bulk of the available codes in Mode 3/A is allocated to ATC. Allocation is often made by reference of blocks of codes or "squawk blocks". A "squawk block" is all those codes which have the same first 2 digits, eg 7500 to 7577, 64 codes. Selected ATC units are allocated specific codes and examples are given in Annex A. Certain units arrange their code allocation to indicate the service being provided by the unit and examples are given in Fig 5.

Breakdown of Unit Codes'

Example 1

Mode 3/A Code 0241 ....

First digit 3/A is the Mode

Second and Third 02 is the Unit (Eastern Radar)

Fourth 4 is the Suite (Four)

Fifth 1 is the track number on that suite and also indicates the console (track 1 of console 4A)

Example 2

Mode 3/A Code 7262 ....

First digit 3/A is the Mode

Second and Third 72 is the Unit (London Military Radar (South))

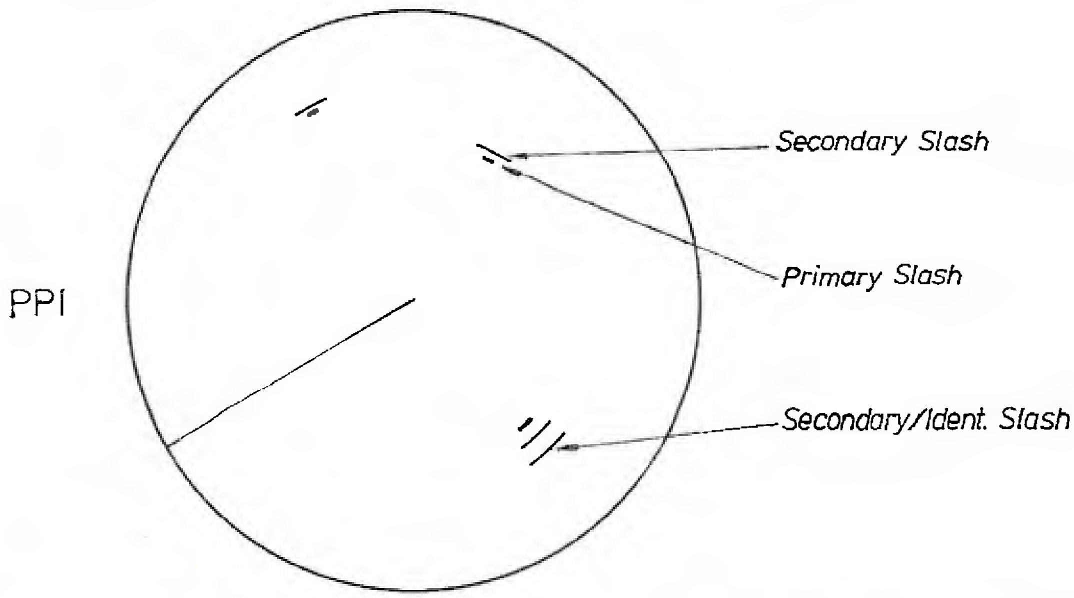
Third and Fourth 26 is the Console (twenty six)

Fifth 2 is the track number (Two)

Fig 5

IDENTIFICATION FEATURE

13. As an aid to aircraft identification a controller can ask an aircraft to "squawk ident"; the pilot actuates an 'Identity' switch and an additional pulse is transmitted in a position, 4.35 micro secs, after the second framing pulse. This pulse normally lasts for about 20 secs. The presentation on the interrogating station's PPI is an additional slash to the normal secondary slash; an example is given in Fig 6. Where the SSR information displayed as a label on the radar picture, the indenting ac will be shown by the whole label pulsing.



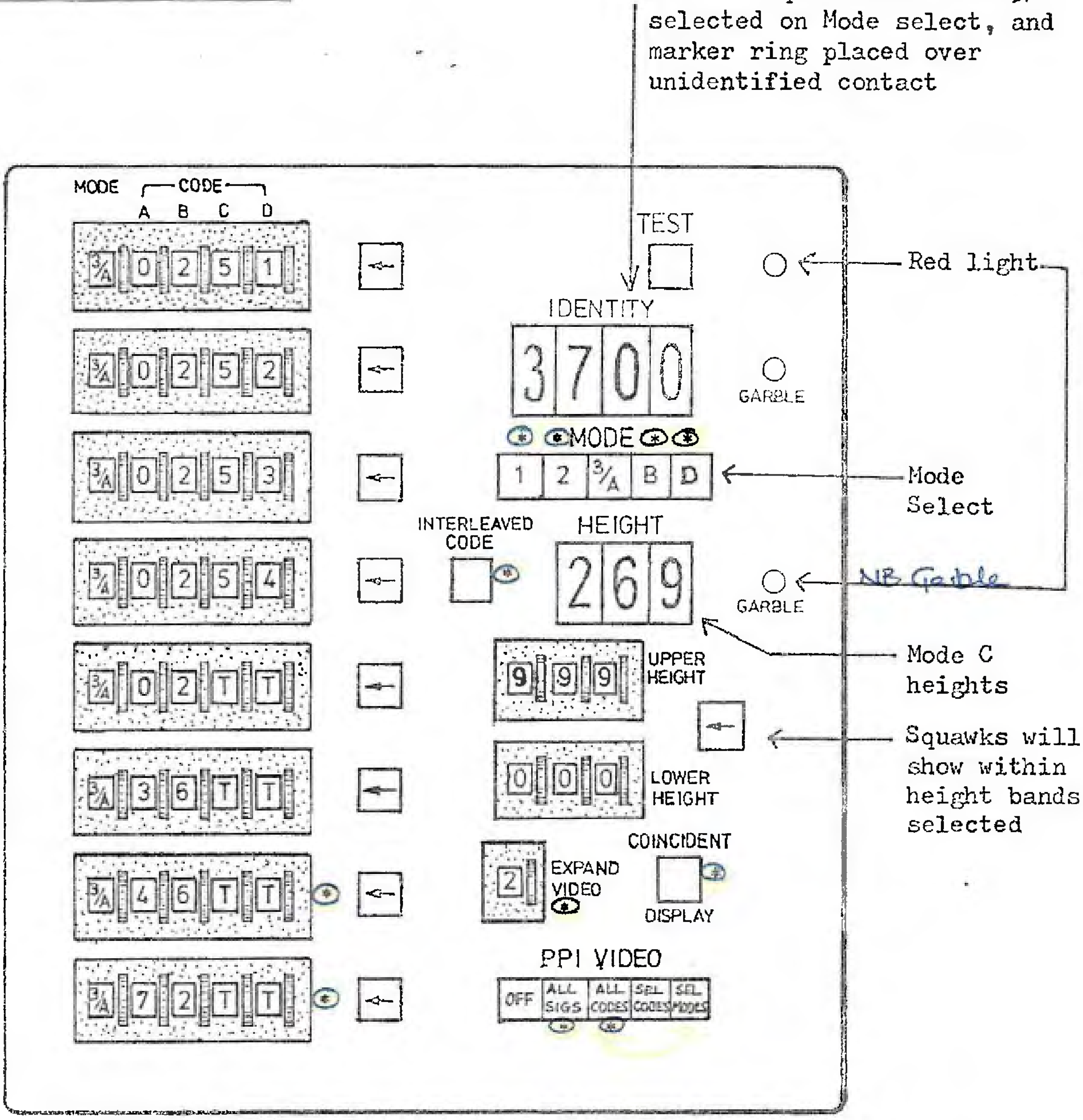
DECODING OPTIONS

14. Active Decoding. This process requires that the code transmitted by the aircraft is actively displayed. To do this, a marker controlled by a joystick, rolling ball unit, or a light pen, etc, is positioned over the aircraft return on the PPI. This causes tihe interrogating station's decoder unit to look only at replies from the specific range and bearing chosen; when a reply from this point is received the decoded reply is presented in numeric form on a digital read-out adjacent to the PPI display.

15. Passive Decoding. Normally the passive decoder will generate a single pulse presentation on the radar PPI related to all aircraft transmitting on the mode selected. A controller may also select presentation on the PPI related to mode and code and as such only aircraft replying on the mode/code required by the controller will be displayed. Other ac, although squawking, are filtered out by the ground equipment responsible for the controller's picture.

16. Decoder Control Panel. Decoder Control Panels are normally situated beside the PPI and active and passive switches/controls and their relevant displays are normally operated from the panel; an example is given in Fig 7.

17. ARTS Decoder Control Panel.



* Note:

1. Items marked with an asterisk are not operational on the ARTS decoder panel.

THE FUTURE OF SSR

18. Mode C. Following verification trials within Eurocontrol during 1981 and the continuing observations of Mode C read-outs associated with A4321, there is an increasing desire amongst air traffic controllers to use the altimeter information from all aircraft for separation. MATO has recommended to NATS that the information should be treated as verified although it is acknowledged that there are areas of greater risk. It has been found, for example, that an error in Mode C transmitted information is 10 times more likely to occur when an aircraft is operating in a non-SSR monitored environment, although errors are still very rare. Furthermore, those errors are very unlikely to develop during flight; they are usually present from take-off. Thus the acceptance of A4321 Mode C may have to be linked with instructions for pilots to obtain verification as early as possible in his flight, even though he may not be under radar service in the open FIR or MTA, by calling his local SSR-equipped ATS unit.

19. Mode Alpha. There are 3 areas in which progress is being made in the use and operations of Mode Alpha SSR. The first is the change in requirement for aircraft to carry SSR; in the near future (1983) all aircraft in CAS will have to carry and operate SSR Mode A and so open the way for an extension of a SSR only control environment. This type of operation will be further encouraged as more and more airfield radars have access to SSR by having their own interrogators or by sharing equipment; this is the second area of change. In the RAF most airfields should have SSR by the mid-1990s. The third major development area is more technical and it concerns the introduction of Monopulse ground equipment to prevent track jitter on the new generation of digital radar VDUs. The system is able to plot an accurate position of the target from just one transponder reply instead of averaging out several replies as previously required.

20. Mode Sierra. In spite of all attempts and future plans, the Mode Alpha-based system will be increasingly beset by problems of garbled responses and "fruiting" as more interrogators are introduced. The cure for these problems is in some form of discrete addressing system; ideally one interrogation will achieve a single reply from one aircraft. Suffice it to say here that the system to be used is ADSEL (ADdress SELectively) using a new Mode called Sierra (Mode S). This system increases the available codes to 16,777,216! The foundations of a full no-voice communications system of air traffic control are apparent in such a system, but it is not due to start being implemented until about 1988/89 and there is no declared intention to do away with controllers. The Americans are looking into an even more sophisticated system that would provide the basis for an Automatic Traffic Advisory Resolution Service (ATARS), but that is another story.

EXAMPLES FROM UK SSR CODE ALLOCATION PLAN - CORRECT AT 1 MAY 82

	FUNCTION/CONTROLLING AUTHORITY
--00	GENERAL PURPOSE 64 CODE FACILITY
0021 0022	FIXED WG) HELICOPTER) RECEIVING SERVICE FROM A SHIP
0023	AC ON SAR DUTIES
0200 - 0277	EASTERN RADAR RNAS PORTLAND
0400 - 0477	RAF LAKENHEATH
0600 - 0677	LJAO , HIGHLAND RADAR
1200 - 1277	LONDON MAS SOUTH, RAF BULMER
3601 - 3677	MIDLAND RADAR SHETLAND RADAR
3740 - 3776	RAF MILDENHALL
4302	RAF NORTHOLT
4305	ROYAL FLIGHT HELICOPTERS
* 4321	CONSPICUITY CODE
* 4322	MILITARY LOW LEVEL (CLIMB OUT) SEEKING RADAR SERVICE
4600 - 4677	BNATSU
4700 - 4777	RAF NEATISHEAD
6060 - 6077	RAC WARTON
6100 - 6177	LONDON MAS NORTH
6201 - 6277	BORDER RADAR, RNAS YEOVILTON RAF WOODBRIDGE, RAF UPPER HEYFORD
6500 - 6577	SCOTTISH MILITARY RAF HONINGTON
7000 - 7077	RAF BENTWATERS/YEOVIL/LOSSIEMOUTH
6001, 6004, 6013, 6024, 6037	EASTERN RADAR CIVIL, THE LAST TWO DIGITS INDICATE THE UAR OVER THE NORTH SEA
7350	ANTENNA TRAILING/TARGET TOWING
7500	HIJACK
7600	RADIO FAIL
7700	EMERGENCY

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