Understanding mode S technology

Stemming from several mid-air collisions in the mid-1980s, mode S has been an integral part of airborne transportation today. Although air traffic is the safest mode of transportation, more in-flight information is needed due to the increase in traffic. Enhanced surveillance and ADS-B address this need.

By Wes Stamper

What is mode S? How does it work and why is it needed? What was wrong with the old mode A and C? What is Flight ID, UF and DF, squitter and elementary surveillance? This article will touch on many aspects of mode S technologies of today and tomorrow. The article will also discuss flight ID, elementary surveillance and UF and DF; explain the details of basic mode S surveillance, how it works and discuss the best practices to verify and test an installation. This discussion will also introduce the new enhanced surveillance, DF17 extended squitter and ADS-B; explain the difference between each of these new technologies and what is needed to verify and test installations.

What is mode S?

Mode S or mode "select," is a new way to interrogate an airframe by using a distinct address, such as an aircraft address, that only a particular airframe will respond. Many years ago, mode A and C were developed for airframe identification and altitude reporting. This was and still is an important component of air traffic control and air space management. As more and more airframes were available to the private and commercial flying community, this basic form of surveillance was overwhelming the capacity of the air traffic control radar beacon system (ATCRBS). Given the technology behind the mode A and C interrogation and reply, there were also problems with false reply uncorrelated in time (FRUIT), seeing replies from another interrogation, and garbling one reply interfering with another. The problem is analogous to attempting to listen to several conversations at the same time. As such, the capacity of the ATCRBS was being taxed to its limit.

ATCRBS also uses the "sliding window" technique to determine the azimuth position of the aircraft. This requires many interrogations and replies, which reduce the target-handling capacity of the ATC secondary surveillance radar (SSR). The mode S system uses a monopulse SSR, which has an electrically narrowed beamwidth, typically 2.5 °. Apart from better azimuth accuracy the monopulse technique reduces the number of interrogations required to track a target, as it theoretically requires only one reply to obtain the azimuth and range of the airframe.

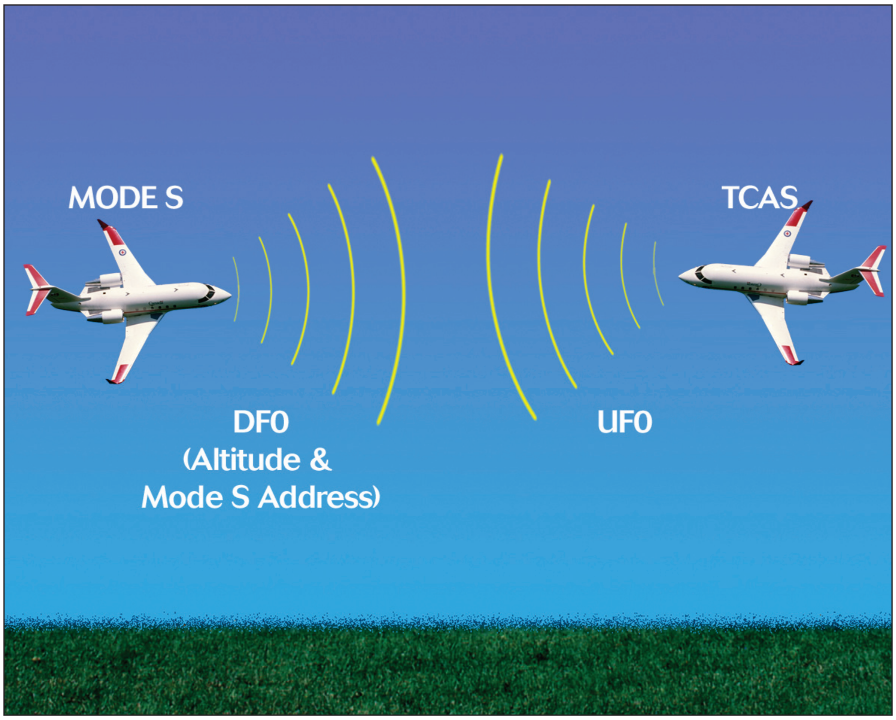

Figure 1. Air to air surveillance.

Where did mode S originate?

The mode S concept was mostly a development of MIT Lincoln Lab with coordinated efforts from the Federal Aviation Administration (FAA), Aircraft Owners and Pilots Association (AOPA) and the transponder manufacturing community. Mode S technology was first developed in the mid-1970s, but was not widely deployed until the early 1980s. The idea was to develop a way of using the same SSR that was being used in mode A and C, but to make it addressable, more accurate and reliable, and operate with greater capacity.

Primary surveillance radar (PSR) is still used to "paint" the airframe with a radar pulse and place a target on the plan position indicator (PPI), which is the display of the ATC. However, the combined use of PSR and SSR allows for better surveillance without major upgrades to the existing PSR/SSR site. This provides an addressable means of gathering the same mode A and C information as well as basic information about the airframe. This new mode S technology is similar to the new digital cellular phones.

Similar to mode A and C, years ago there was the analog cellular phone, which allowed basic communications with minimal features. The current digital cellular phone has the same basic communication but affords more site capacity, better reliability and more capabilities such as text messaging, Internet access and global positioning system (GPS) location information. The same holds true for mode S surveillance. The mode S-equipped airframe can now report identity, intent, capability and location.

How does the interrogation and reply actually work?

The basic ATCRBS system relies on pulsed RF as its means of communications. These pulses are 0.8 µs wide and vary from 8.0 µs to 21 µs spacing for mode A and C respectively. The SLS (P2) pulse is also transmitted omnidirectionally and is used to suppress any replies to side lobe interrogations. The mode S SSR will interrogate using a 1030 MHz carrier with differential phase shift keying (DPSK) modulation. DPSK allows the interrogation frequency to have much more efficiency in sending information without interfering with mode A and C interrogations. DPSK also allows for up to 4 MBps of data. As the 1030 MHz, DPSK signal sends out the interrogation, the airframe will receive it, verify the request and integrity of the signal, and reply using a 1090 MHz carrier with pulse positioning modulation (PPM) transmission.

SSR is central to the mode S system. Mode S interrogations are generated at a rate of 50 times per second or 50 Hz pulse repetition frequency (PRF) and approximately 230 Hz for mode A/C interrogations. The reply will happen at the same PRF although mode S SSR has the ability to tell the mode S transponder not to reply to every mode S interrogation it receives. Once the SSR has received the reply it will decode the mode (A, C or S) and demodulate the information within each mode.

There are three interrogation types in a mode S SSR system:

1. *ATCRBS all call*: This interrogation consists of P1, P3 and a 0.8 µs P4 pulse. P2 SLS is transmitted as normal. All ATCRBS transponders reply with the 4096 identification code for mode A interrogations and altitude data for mode C. Mode S transponders do not reply on this interrogation.

2. *ATCRBS/mode S all call*: This interrogation is identical to the former except P4 is 1.6 µs long. ATCRBS transponders reply with the 4096 code or altitude data as per the ATCRBS all call. Mode S transponders reply with a special code, which contains the identity and the aircraft's discrete address.

3. *Mode S discrete interrogation*: This interrogation is directed at a specific mode S transponder-equipped aircraft. The interrogation consists of P1, P2 and P6. P2 is transmitted via the directional antenna and hence is the same amplitude as P1 and P3. This effectively suppresses ATCRBS transponders from replying. P6 is actually a DPSK data block that contains either a 56-bit or 112-bit message. The DPSK modulation produces a spread-spectrum signal, which has immunity to interference.

When the transponder receives a valid mode S discrete interrogation, it will return a reply 128 µs after reception. The reply is transmitted on 1090 MHz and uses a 56-bit or 112-bit PPM transmission.

Each mode S interrogation will have a 24-bit address unique to the aircraft as well as a 24-bit parity check for validation. In basic mode S surveillance, the information is limited to altitude reporting (DF0), aircraft identification (DF4) and basic airframe information (DF11). The SSR is the main component of the interrogation and reply. The interrogation happens about 50 Hz PRF. The reply will happen at the same PRF. Once the SSR has received the reply it will decode the mode (A, C or S) and demodulate the information within each mode.

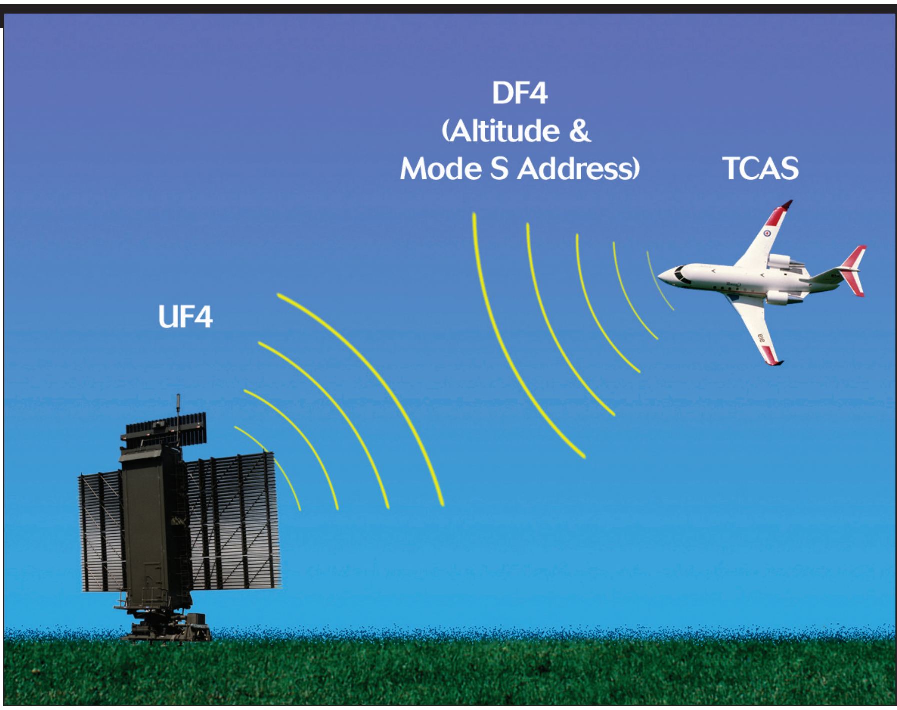

Figure 2. Ground station request.

What is squitter?

A definition of squitter is a reply format transmission without being interrogated. These "unsolicited replies" or squitters are used to provide TCAS 2-equipped airframes with the discrete address of the squittering airframe, to enable the TCAS 2 system to acquire and track the airframe using mode S formats UF/DF0 and UF/DF16.

Squitter has its origins in distance-measuring equipment (DME) transmissions. The DME ground station would broadcast unsolicited replies or squitters. When the airborne DME interrogator was in range, the squitter would be seen and the DME interrogator would then transmit a range interrogation and receive range replies from the DME ground station. This served to limit unnecessary transmissions over the air and optimized DME ground station-handling capability. TCAS 2 systems use mode S squitters in a similar fashion; the TCAS just listens for the DF11 squitters, which contain the sending aircraft's discrete address, thereby reducing the need to interrogate over the air. The discrete address, once obtained, is placed on the TCAS 2 processor's roll call of addresses for ongoing tracking. Mode S technology has two types of squitter, a short (56 bit) DF11 acquisition squitter and the extended (112 bit) DF17 squitter.

UF and DF

The functional components of mode S are uplink format (UF) and downlink format (DF). UF is a specific interrogation originating from SSR or another airframe asking specific, addressable information about that airframe. DF is the reply from the airframe in regard to the UF interrogation. UF 0, 4, 5, 11 and 16 make up basic surveillance. Basic surveillance messages are comprised of the airframe address, parity bits and a 56-bit data word known as "short" interrogations and replies.

UF0 is a short air-to-air surveillance for TCAS/ACAS (Figure 1). The DF0 reply will include the mode C altitude as well as the mode S address. To test DF0, its altitude reply is compared to the mode C altitude and the mode S address for verification. Also encoded in the DF0 reply is the vertical status (VS) bit, the reply information (RI) field. The VS bit will indicate a 1 if the airframe is on the ground and a 0 if it is on the air. The RI field is a four-bit word containing the airframe's true speed capability and type of reply to the interrogating airframes.

UF4 is a short, ground station request for altitude similar to the UF0 request, but initialized by the ground station (Figure 2). Testing the DF4 reply is verified against the mode C altitude and the mode S address for validity. Also encoded in the DF4 reply is the flight status (FS) field, downlink request (DR) field, utility message (UM) and the altitude code (AC) field. The FS field is a three-bit word reflecting eight different conditions of airborne, alert and special position indicator

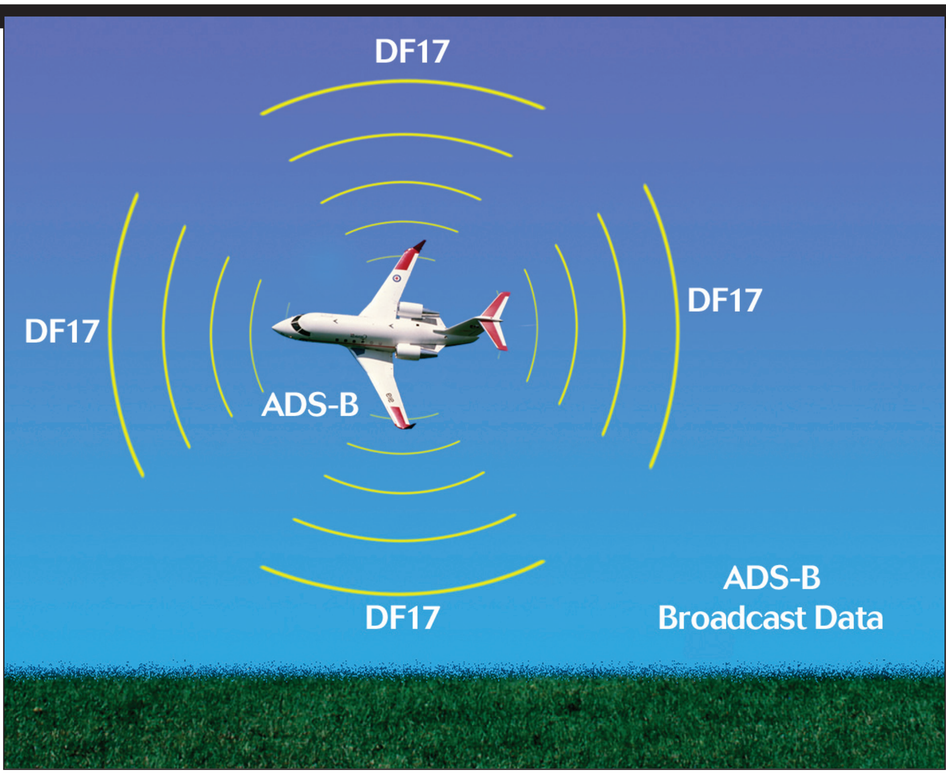

Figure 3. ADS-B broadcast data.

status (FS) and altitude code (AC). These parameters are compared to the DF11 reply for validity. A transponder that does not have an active subsystem that will accept comm A data will not reply to a UF20 interrogation.

UF21 is the long from of a UF5. Where the DF5 is 56 bits long, the DF21 is 112 bits long. The DF21 reply is also known as comm A identity request. The DF21 reply also contains a 56-bit message field for transferring downlinked aircraft parameters (DAPS). To properly test the DF21 reply, the UF21 must contain a reply request (RR) of 17, a designator identifier (DI) of 7 and a reply request subfield (RRS) of 0. The working component of the DF21 reply is the comm B message field or MB. Contained in the MB field is aircraft address (AA), downlink request (DR), flight status (FS) and identification code (ID). These parameters are compared to the DF11 reply for validity. A transponder that does not have an active subsystem that will accept comm A data will not reply to a UF21 interrogation.

(SPI) status of the airframe. The DR field is a five-bit word that will contain the request to downlink certain airframe information. The UM field is a six-bit word that contains transponder communication status information. The AC field is a 13-bit word that contains the altitude of the airframe with special encoding for feet or metric units and if the altitude resolution is 25 feet or 100 feet.

UF5 is a short, ground station request for the airframe identity. The DF5 reply is the airframe's identification and is compared to the mode A 4096 code for validity. Also encoded in the DF5 reply is the flight status (FS) field, downlink request (DR) field, utility message (UM) and the identification (ID) field. The FS field is a three-bit word reflecting eight different conditions of airborne, alert and special position indicator (SPI) status of the airframe. The DR field is a five-bit word that will contain the request to downlink certain airframe information. The UM field is a six-bit word that contains transponder communication status information. The ID field is a 24-bit word that contains the mode A identification of the airframe.

UF11 will request the airframe's mode S address. The DF11, or all-call reply, will reply with the airframe address (squitter address) as well as the capability (CA) field, parity/interrogator identifier (PI) field, the interrogator identifier (II) and surveillance identifier (SI). The CA field is a three-bit word that contains the communication capabilities of the transponder. The PI field is a 24-bit word that will report the interrogator identification code with a parity overlay. The II field is a four-bit word, from 0 to 15, containing the identification code of the interrogator. The SI field is a six-bit word, from 0 to 63, used to identify the types of surveillance.

UF16 is a long, air-to-air surveillance for ACAS and is the long form of a UF0. Where the DF0 is 56 bits long, the DF16 is 112 bits long. The DF16 reply will have in it the mode C altitude, as well as the mode S address. Testing DF0, the altitude reply is compared to the mode C altitude and the mode S address for verification. Also encoded in the DF16 reply is the vertical status (VS) bit, the reply information (RI) field and the altitude code (AC) field. The VS bit will indicate a 1 if the airframe is on the ground and a 0 if it is in the air. The RI field is a four-bit word containing the airframe's true speed capability and type of reply to the interrogating airframes. The AC field is the mode S altitude that is compared to the mode C reply for validity. Also in the DF16 is the message comm V (MV) field. This field contains information used in air-to-air exchanges (coordination reply message).

UF20 is the long form of a UF4. Where the DF4 is 56 bits long, the DF20 is 112 bits long. The DF20 reply is also known as comm A altitude request. The DF20 reply also contains a 56-bit message field for transferring downlinked aircraft parameters (DAPS). To properly test the DF20 reply, the UF20 must contain a reply request (RR) of 17, a designator identifier (DI) of 7 and a reply request subfield (RRS) of 0. The working component of the DF20 reply is the comm B message field (MB). Contained in the MB field is aircraft address (AA), downlink request (DR), flight

Uplink extended length messaging (UELM)

This is known as comm C capability of a transponder. A transponder must be a level 3 to accept a UELM message. UELM operates over UF24, which allows for long data messages to be sent from the ground station to the airframe. UF24 works similar to any other interrogation with one exception. The UELM message is capable of up to 16-bit to 80-bit message segments for this extended message. The working component of UELM is the comm C message (MC) field. This MC field works in conjunction with the number of C (NC) or segments to allow for the extended message.

Downlink extended length messaging (DELM)

This is known as comm D capability of a transponder. A transponder must be a level 4 to transmit a DELM message. DELM operates over DF24, which allows for long data messages to be sent from the airframe to the ground station. DF24 works similar to other interrogations with one exception. The DELM message is capable of up to 16-bit to 80-bit message segments for this extended message. The working component of DELM is the comm D message (MD) field. This MD field works in conjunction with the number of D (ND) segments to allow for the extended message.

What is flight ID?

Flight ID has its origins in the International Civil Aeronautics Organization (ICAO). The flight ID is an eight-character identification that is entered by the pilot usually via a flight deck CDU. The flight ID may contain the company-assigned number for that particular flight. If the company-assigned number is not available or not used, the flight ID then becomes the aircraft tail number. The flight ID supplements the unique 24-bit aircraft discrete address and is used by ATC for monitoring purposes.

What level is the transponder being tested?

The level of a transponder is an important point when testing an installation. The level reports the capabilities of the transponder. A level 1 transponder is one with basic surveillance capabilities. This is UF0, UF4, UF5 and UF11 reporting. A level 1 transponder will have no provision for datalink capabilities or extended length messaging. A level 2 transponder will have all the features of a level 1 with capabilities for UF16, UF20 and UF21 or comm A/B protocol. Most transponders installed today are level 2 capable. The level 3 transponder adds uplink extended length messaging (UELM) to the level 2 transponder. The level 3 transponder is capable of receiving a UELM from the ground interrogation using comm C (UF24) format, but does not need to reply directly. The UELM reply will include a summary of the interrogation. A level 4 transponder is the most advanced in its capabilities. This transponder adds downlink extended length messaging (DELM) to the level 3 transponder. The DELM is used similar to the UELM except the DELM is air to ground transmissions.

Comm B and BDS

These parameters make up an important part of elementary and enhanced surveillance. Comm B is the integral part of DF20 and DF21 that has the message B (MB) field within its reply. The MB message field may contain downlink data requested from the transponders' BDS registers. These BDS registers or comm B designated subfield registers contain information about the status, intent and location of the airframe.

What is elementary surveillance?

Elementary surveillance is as easy as 1, 2, 3 or BDS 1, 2 and 3. This concept is driven largely in part by EuroControl, that takes basic surveillance (UF0, 4, 5, 11) a step further in adding the features of DF20 comm B communications for datalink and identification of the airframe. Elementary surveillance is made up of several new components. These are 25-foot resolution altitude decode, interrogator identification (II) and surveillance identification (SI) verification, flight status, data link capability report (BDS 1,0), GICB report (BDS 1,7), aircraft identification (BDS 2,0), and ACAS active resolution advisor report (BDS 3,0). A EuroControl mandate stated that elementary surveillance installations started March 31, 2003 with a transitional period up to March 31, 2005.

What is enhanced surveillance?

Enhanced surveillance, as in elementary surveillance, is as easy as 4, 5, 6—that is BDS 4, 5 and 6. Take the concept of elementary surveillance and add new aircraft intent reporting fields. These fields are selected vertical intent (BDS 4,0), track and turn report (BDS 5,0) and heading and speed report (BDS 6,0). The selected vertical intent report (BDS 4,0) is used to indicate such items as the barometric altitude of the airframe, the selected altitude of the mode control panel or flight control unit (MCP/FCU) and the flight management system (FMS). The target altitude of the aircraft also reports what altitude the aircraft is intending to use. The track and turn report (BDS 5,0) will indicate the roll angle, true track angle and rate, ground speed and true air speed of the aircraft. The heading and speed report will reflect the indicated air speed and mach, the barometric altitude rate, the magnetic heading and inertial vertical velocity.

The level of a transponder is an important point when testing an installation.

What is DF17 extended squitter?

The concept of DF17 extended squitter is similar to elementary and enhanced surveillance with one exception: DF17 is a squitter and does not need an interrogation. Therefore, the DF17 will report its information regardless of any ground station or airframe asking. DF17 extended squitter is supported by the FAA and will make an important part of automatic dependent surveillance—broadcast (ADS-B). DF17 extended squitter includes airborne position (BDS 0,5), surface position (BDS 0,6), extended squitter status (BDS 0,7), identity and category (BDS 0,8) as well as airborne velocity (BDS 0,9) reporting. Airborne position (BDS 0,5) includes the longitude and latitude of the aircraft, the barometric altitude, the GNSS (GPS derived) height and surveillance status. Surface position is similar to airborne position with the longitude and latitude of the aircraft, and the movement and heading of the aircraft. The extended squitter status report will reflect the surface squitter rate, altitude type and extended squitter status. BDS 0,8 or identity and category will report the ADS-B emitter category type ranging from "no reporting" to surface vehicle to space vehicle. The last of these, and possibly the most intense, is airborne velocity. This will report the east/west and north /south velocities, heading, vertical rate and altitude source, the difference between the barometric and GPS altitude, the IFR capability and airspeed.

What is ADS-B?

As previously discussed, DF17 is the integral and working portion of automatic dependent surveillance broadcast (ADS-B) (Figure 3). Breaking down the meaning of the terms: automatic—there is no interrogation needed to start the data or squitter coming from the transponder; dependent—as it relies on onboard navigation and broadcast equipment to provide information to other ADS-B users; and surveillance—it is a means of automatic surveillance and traffic coordination. Some of the benefits of ADS-B technology are better use of airspace, improved aircraft-on-ground surveillance and better safety for traffic avoidance and conflict management.

Conclusion

Will the air transport industry of tomorrow truly be a "free flight" community, without the need for ATC or ground surveillance? This is another discussion entirely. However, mode S will continue to evolve to meet the needs of an ever-expanding airborne community. The notion of small private aircraft and large air transports sharing the same airspace without the ever-watchful eye of ATC may be a far-fetched idea for the near term, but may become a reality in the future. Only 50 or 60 years ago, pilots coined the original phrase of IFR or "I Follow Road" for guidance and surveillance. All the while the pilots are relying on radio contact and visual acquisition for collision avoidance. Today, we rely upon high-tech electronics to autonomously navigate our airspace. What will the next 50 years reveal? For now, an understanding of the mode S of today and the new technologies of tomorrow is needed to provide for a safe flying environment. **DE**

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