



AEROSPACE STANDARD

AS6171™/3

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Techniques for Suspect/Counterfeit EEE Parts Detection by X-Ray Fluorescence Test Methods

RATIONALE

Since counterfeit electrical, electronic, and electromechanical (EEE) components are likely to have some level of material difference from the genuine components, techniques that identify the chemical elements in different areas of a part are essential to benchmarking authentic parts (exemplars) and comparing them to parts under consideration. X-ray fluorescence (XRF) is one such technique that can be applied both to the external surfaces and internal elements of a part. The method itself is nondestructive by nature.

AS6171/3 has been reaffirmed to comply with the SAE Five-Year Review policy.

INTRODUCTION

Because many methods of counterfeiting of EEE components involve change of material from the original part, X-ray fluorescence (XRF) spectroscopy can provide a method of inspection of parts and detecting differences in their material composition. The method has been used extensively to detect nonconforming parts in electronics and in many other product areas. The implementation of RoHS¹ requirements of the European Union and similar laws in other countries, resulted in wide spread use of XRF testing to confirm that electronic part leads do or do not contain lead (Pb). This document provides an introduction to the theory and practice for application to counterfeit electronic part detection.

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¹ Restrictions on Hazardous Substances

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1. SCOPE

XRF technique for counterfeit detection is applicable to electrical, electronic and electromechanical (EEE) parts as listed in AS6171 General Requirements. In general, the detection technique is meant for use on piece parts prior to assembly on a circuit board or on the parts that are removed from a circuit board. The applicability spans a large swath of active, passive and electromechanical parts.

If AS6171/3 is invoked in the contract, the base document, AS6171 General Requirements shall also apply.

1.1 Purpose

The purpose of this document is to provide information and instructions on how to use XRF as a technique to verify the materials and finishes of EEE parts to compare with the original design, construction and material requirements. The process of detection is based on identification of elements (or absence thereof) in a component. The indication of counterfeit risk can also be based on the presence of and concentration levels of materials under consideration. The counterfeit detection process using XRF can be applied to components as received or on delidded, decapsulated, or otherwise prepared parts. For reliable decision making, findings from XRF analysis need to be compared with material composition information of appropriate exemplars, compared with each other in the lot, or compared with the original manufacturer's documented specifications.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

- [1] AS5553, Fraudulent/Counterfeit Electronic Parts; Avoidance, Detection, Mitigation, and Disposition.
- [2] AS6171, Test Method Standard, General Requirements, Suspect/Counterfeit, Electrical, Electronic, and Electromechanical Parts.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

- [1] JEDEC, JESD 213, Standard Test Method Utilizing X-ray Fluorescence (XRF) for Analyzing Component Finishes and Solder Alloys to Determine Tin (Sn) - Lead (Pb) Content.
- [2] Naval Air Systems Command, "Solder Alloy Analysis: X-ray Fluorescence Test Equipment Evaluation Report," NAVAIR in conjunction with Crane Division, Naval Surface Warfare Center, Defense Logistics Agency, July 2009.
- [3] Beckhoff, B.; Kanngießer, B.; Langhoff, N.; Wedell, R.; Wolff, H. (Eds.), Handbook of Practical X-ray Fluorescence Analysis, Springer 2006.
- [4] NAS 410, Certification and Qualification of Non-Destructive Test Personnel, AIA.
- [5] ISO, ISO 17025, General Requirements for the Competence of Testing and Calibration Laboratories.

- [6] MIL-STD-1580B, Destructive Physical Analysis for Electronic, Electromagnetic, and Electromechanical Parts.
- [7] MIL-PRF-38535, Integrated Circuits (Microcircuits) Manufacturing, General Specification for (w/Amendment 1) Revision: J, Dated: 14 May 2012.
- [8] ASTM B568-98 (2009), Standard Test Method for Measurement of Coating Thickness by X-ray Spectrometry.
- [9] ISO 3497:2000, Metallic coatings - Measurement of coating thickness - X-ray spectrometric methods.

2.3 Terms and Definitions

See 2.2 of AS6171 General Requirements.

2.4 Acronyms and Abbreviations

See 2.3 of AS6171 General Requirements.

3. DESCRIPTION OF METHODOLOGY/PROCEDURE

X-ray Fluorescence (XRF) is a fast and simple method to detect material composition. Its most notable qualities include no, or minimal, sample preparation, nondestructive analysis, and compatibility with solid, liquid, and powdered samples. XRF spectrometers range from light hand-held devices to table-top machines, and floor mounted instruments employing liquid nitrogen. The principle of operation is detecting the energy level of ejected electrons under incident X-ray. Fluorescence refers to a phenomenon where absorption of radiation of one type of energy results in emission of radiation of a different energy. Figure 1 shows the basic principle and Figure 2 shows a schematic of an XRF system. In the diagram, K, L, and M denote the three innermost shells and K_{α} and K_{β} are the energy emissions that result from electrons transitioning between shells L and K and between shells M and K respectively.

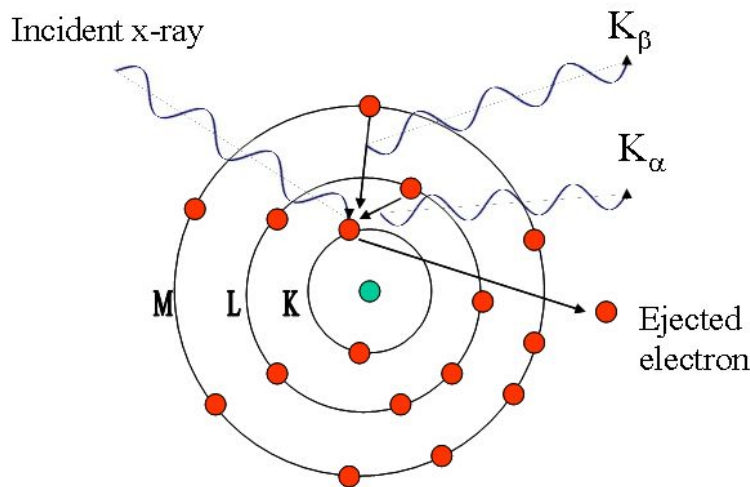


Figure 1 - XRF principle of operation

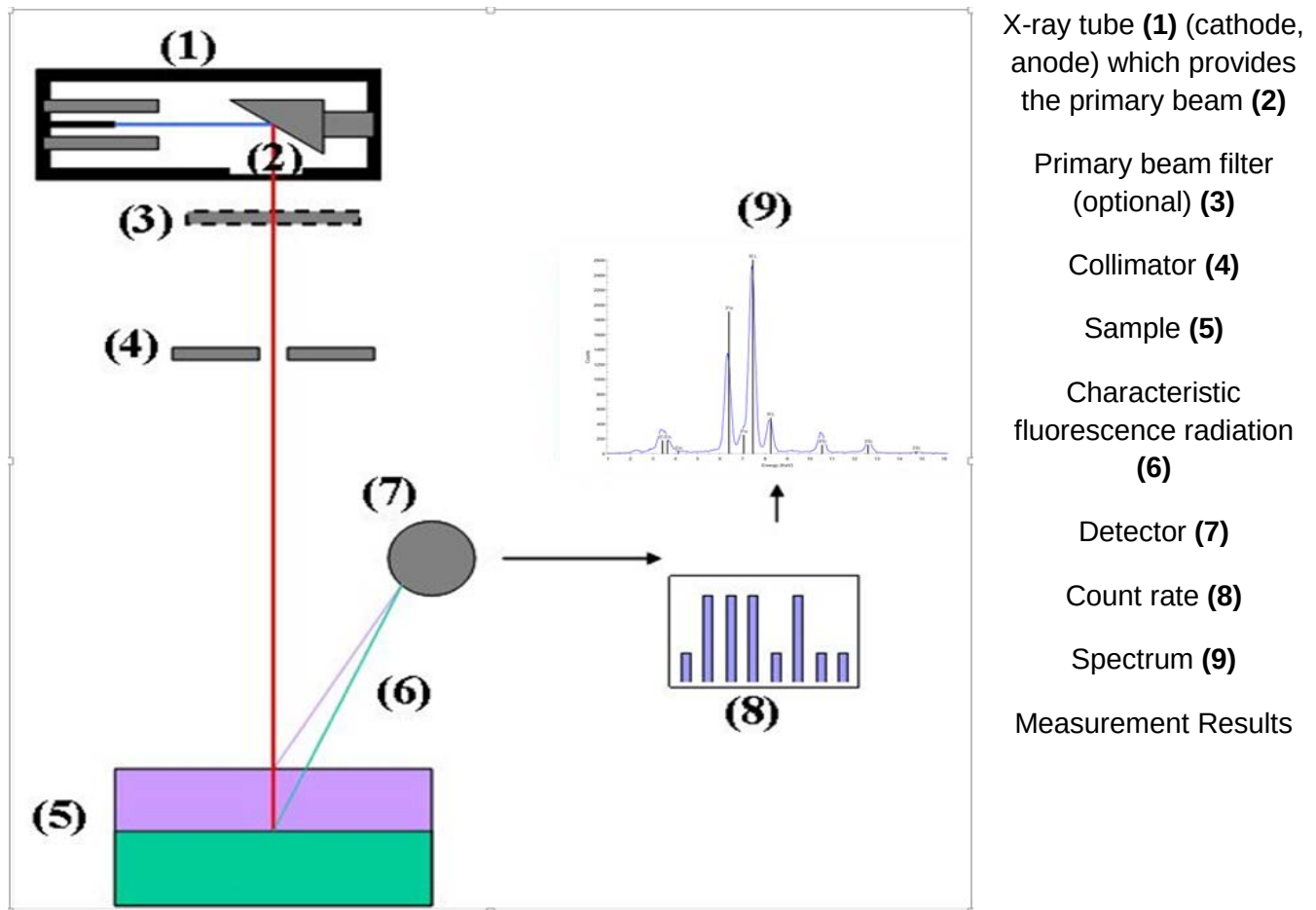


Figure 2 - Schematic of an XRF system

Principle of X-ray Fluorescence

Incident electromagnetic waves (X-rays) of sufficient energy excite electrons in an atom's inner orbital (core electrons). The excited electrons are ejected from the inner orbital. Electrons from an outer orbital then move to the inner orbital to fill the vacancies. During this transition, the electron emits an X-ray photon whose energy is equal to the difference between the two energy levels involved in the transition.

Principle of operation of an XRF spectrometer:

- Incident X-ray beam strikes sample
- Excitation of characteristic lines (X-ray fluorescence)
- Element specific characteristic radiation is detected and a spectrum is created
- Software evaluates spectrum for presence/absence of elements

3.1 Material Control/ESD Handling

Material control and ESD handling shall conform to 3.9.5 of AS6171 General Requirements.

3.2 Additional Considerations

This section outlines the cautions to be taken and limitations of the XRF counterfeit risk detection technique. This section also discusses the needs for additional techniques for confirming or invalidating the results of XRF techniques. Some of technical limitations for the XRF technique are also discussed.

XRF assumes a homogeneous matrix in order to quantify the presence of any given element in the sample. In heterogeneous samples such as electronic components, XRF yields relative qualitative results on the presence of elements. When the zone of analysis on the electronic component is locally homogeneous and the XRF beam size and focus is on that homogeneous area, the results can be accepted as being from a homogeneous matrix.

Using a plating thickness or plating thickness/composition mode of XRF measurement can provide useful information and assist in the analysis of the component. Device construction information of base material, plated layers, and top finish layer can be analyzed/compared to OCM design, variation between devices, or to historical variations in materials such as changes in connector contact plating (Au/Ag/Cu versus Au/Cu versus Au/Ni/Cu) or solder finish (Sn versus Sn-Pb versus other lead free). Knowledge of the top layer thickness and its contribution to the spectrum will provide useful insight during the analysis.

There is potential for false positive and false negative detection of elements. For example, when using XRF in the plating thickness/composition mode, sample elements absent from the measurement application file and incorrectly identified layers in that file can cause erroneous detection. The analyst should review the raw instrument data in the form of an X-ray energy spectrum to verify the analyzer's reading. The X-ray energy spectrum shows what elements should be present in the plating thickness/composition mode report with X-ray peaks present at known energies, and if these elements were not correctly detected in the report it can quickly be determined from the spectrum that the measurement application file needs revision (refer to Figures 3 and 4).

While XRF is capable of detecting elements from Aluminum to Uranium, the calibration set on most instruments is generally limited to measuring somewhere between 20 to 25 elements at one time. With complex matrices there is the potential for false positives or negatives if the instrument is not calibrated for all the elements that occur in the sample. Analysis of the raw data produced by the instrument, in the form of an X-ray energy spectrum, may be consulted to verify the instrument's reading. Additionally, reference techniques such as Induction-Coupled Plasma (ICP) or SEM-EDS can be used to validate XRF results.²

4. TEST EQUIPMENT AND CALIBRATION

4.1 Equipment

This section specifies minimum XRF equipment specifications for suspect part identification. The type of XRF equipment chosen for the evaluation is influenced by several factors including the component location to be tested, whether or not the component to be tested is loose or installed onto a circuit board assembly, and the size or surface area of the component lead or termination area.

4.1.1 Benchtop XRF

The overall power of the system is important to ensure that the appropriate depth of the material is scanned and enough energy is available to reach the proper levels of shells. In order to assure proper function, periodic hardware checks should be performed on the instrument per the manufacturer's specifications. It is also recommended that the standard operating procedures include frequently analyzing known reference materials to verify the instrument's accuracy.

² All of the analytical instruments mentioned (ICP; SEM-EDS) are subject to recording false positive or negative results. Proper training by the manufacturers of analytical instrumentation including XRF is required to minimize this problem.

The system needs to be based on an X-ray tube with an accelerating voltage set at minimum of 40keV. Either a proportional counter or a semiconductor detector can be present in these units. To facilitate examination of parts of different sizes, multiple collimators are necessary. (A collimator needs to be selected that is smaller than the area that needs to be measured.) Using Benchtop XRF equipment is the preferred method for counterfeit parts detection, as outlined in the Selection Summary of Type of XRF Tool.

4.1.2 Hand-Held XRF

For hand-held XRF applications, the instrumentation should be an energy dispersive spectrometer with a Silicon Drift Detector or Silicon Pin Diode Detector of resolution 285 eV or lower. A model based on an X-ray tube with variable accelerating voltage is preferable to efficiently excite a wide range of elements. X-ray tube anode material will vary. Utilizing a fixture to eliminate unintended movement of the hand-held spectrometer is also recommended.

4.2 Analysis Software

The associated software should be able to analyze layered structures and generate thickness and composition results. Thickness and composition standards are necessary to verify the accuracy of the results. For example, SnPb foil standards are available that are certified to thickness and to a composition that is 97% Sn and 3% Pb. Bulk Solder standards are required when checking homogeneous Sn based materials. In cases where bulk analysis can provide data necessary for counterfeit risk assessment or only bulk analysis is practical to perform, software capable of such analysis will be sufficient.

4.3 Selection Summary of Type of XRF Tool

Advantages of a hand-held XRF are portability, ability to inspect samples too large to fit in a benchtop XRF instrument, and lower cost. Disadvantages of a hand-held XRF include beam size, bulk analysis spectrum, beam focus, and instrument movement. The beam size on a hand-held XRF is typically larger than 1.0 mm whereas a benchtop XRF beam size is at least an order of magnitude smaller. The collimator size shall be smaller than the region being analyzed and the focus shall be within that region. A general guideline is that the beam diameter should be one-third to one-half the width of the area of interest. Typically, the area of interest on electronic components is small. Hand-held XRF systems were developed to quickly measure large surfaces such as painted walls, metal scrap, and soil samples on site. They perform bulk material analysis by evaluating the spectrum of the bulk material. Unless the outer plating is very thick, the spectrum reflects the outer plating, the base material, and any intermediate layers. Estimating composition of a plated surface versus the base material from a bulk analysis spectrum requires complex software. Hand-held systems are designed to be in contact with the device under test (DUT). The beam and detector are focused and in alignment when the hand-held system is in contact with the DUT. This can be an issue with small components that may be ESD sensitive, whose area of interest is smaller than the beam size, devices mounted on a board, or where the area of interest cannot be accessed by the measurement end of the hand-held XRF. The hand-held system should also be held steady since movement during the measurement can induce error. Many manufacturers offer an optional stand that minimizes movement of the hand-held device during operation to gather the spectrum for decision making. A hand-held XRF should only be used if the area of interest is at least twice the beam diameter and if bulk spectrum analysis is sufficient to gather information needed to make a knowledgeable decision concerning potential for counterfeiting.

The benchtop XRF has the advantage of increased capability and accuracy. The main disadvantage is cost. A benchtop XRF is ideally suited to measure electronic components based on its small beam size, stable specimen platform, and plating thickness plus composition measurement capability. Along with bulk material spectrum analysis, a benchtop system uses software that allows it to measure plating thickness and analyzes the plated surface separately from the base material. Some software also provides a measurement accuracy indication that automatically can warn the operator when the spectrum is different than expected. The Silicon Drift detector has the best resolution at 145 eV, while the PIN Diode detector is also good at 285 eV. The resolution of an XRF system with a Proportional Counter type detector is limited in comparison at 1200 to 1800 eV. Consequently, a benchtop XRF with either a PIN Diode detector or a Silicon Drift detector will have higher resolutions compared to a Proportional Counter type detector. While a Proportional Counter costs less and provides a larger standoff distance, its lower X-ray energy resolution may not be able to resolve peaks resulting from multiple elements with similar X-ray energies. This failure to resolve elements can cause quantitative analysis algorithms to miss some elements present in large quantity while over-reporting the quantity of the remaining elements. Even an experienced operator will be unable to perform some evaluations where the elements are close together or present in small or trace amounts.