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HISTORY OF THE QUARTZ OSCILLATOR-PLATE INDUSTRY, 1941–1944

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In 1881, Pierre and Jacques Curie discovered that quartz and certain other low symmetry crystals developed positive and negative electrical charges at the ends of the polar $X=a$-axes when subjected to properly directed pressure. In the following year, G. Lippmann suggested that such crystals would become mechanically deformed if subjected to an electrical field, and this converse piezoelectric effect, so-called, was experimentally verified by the Curies. The effect remained hardly more than a laboratory curiosity for many years until P. Langevin in Paris, during World War I, devised quartz plates for sending out and detecting underwater sound waves. At about the same time, A. M. Nicholson of the Bell Laboratories experimented with phonograph pickups and microphones constructed of Rochelle-salt crystals. The application of the piezoelectric effect to radio, however, did not come until 1921, when Professor W. G. Cady of Wesleyan University showed that quartz plates could be used to control vacuum tube oscillators. In this application, the alternating electrical field generated by the vacuum tube radio circuit is applied to a quartz plate, properly cut and mounted and so dimensioned that one of its natural frequencies of mechanical vibration coincides with the oscillations of the circuit, and the frequency of transmission or reception is thereby stabilized and precisely controlled. Some types of quartz oscillator-plates used by the Armed Services are shown in Fig. 1. Quartz, rather than other natural or artificial crystals, some of which give much

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more pronounced piezoelectric effects, is employed for the purpose primarily because of its chemical and physical stability, high elasticity and availability. An increasing demand for crystal-controlled oscillators and filter circuits developed during the 1930's and approximately 50,000 quartz oscillator-plates were manufactured in the United States during 1939.

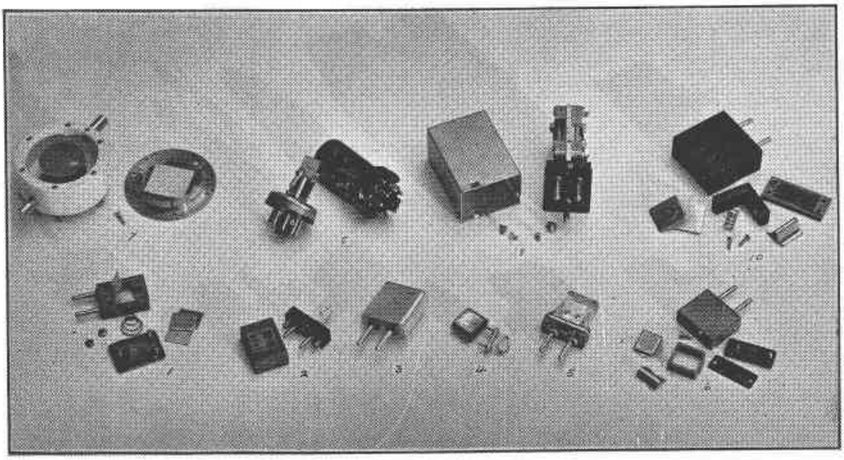

FIG. 1. Some types of mounted quartz oscillator-plates for radio use. No. 1, FT-243 type clamped crystal, showing component parts. No. 2, FT-241 wire suspension metal-plated CT-cut crystal. No. 3, hermetically sealed CR-1 crystal in solder-sealed all-metal holder. No. 4, CR-7 type, plated wire suspension BT-cut crystal. No. 5, hermetically sealed CR-1 type crystal in solder-sealed Pyrex glass holder. No. 6, CR-1 clamped type crystal in phenolic holder. No. 7, FT-164 AT-cut crystal in variable air gap holder. No. 8, metal-plated wire suspension DT-cut crystal. No. 9, MX-12 AT-cut clamped crystals in dual mounting. No. 10, DC-11 type clamped crystal, showing L-shaped adapter to accommodate small sized crystal within the holder.

With entrance of the United States into World War II in 1941 the Armed Services demanded almost fantastic quantities of oscillator plates —literally tens of millions. Part of the needs of our Allies also were to be supplied by Lend-Lease. Rapid and certain communication is the keystone of global war, and many thousands of aircraft, ships, tanks or other mobile or stationary ground units were to be fitted with radios, each with its complement of "crystals." The problem of supply created an industrial problem of the first magnitude. The responsibility for initiating and guiding procurement for the Army and Air Forces rested largely in the Quartz Crystal Coordination Section, General Development Division, Office of the Chief Signal Officer, War Department. This group was activated under a directive of March 5, 1942, from Major General (then Brigadier General) Roger B. Colton, Chief of the Material Branch, U. S. Army Signal Corps, which charged the General Development Division, among other duties, to "Take necessary steps to handle the crystal problem and successfully meet it." The Quartz Crystal Coordination Section had its headquarters in Temporary Building A, later in the Pentagon Building, Washington, and comprised a small number of civilian and Army technicians and scientists working under the direction originally of Colonel (then Lieutenant Colonel) J. D. O'Connell. This group carried the brunt of the work during the first year or so of the crystal program. The Crystal Section was aided in its task by the Crystal Branch of the Signal Corps Laboratories at Fort Monmouth, New Jersey, and later by the Aircraft Radio Laboratory at Wright Field, Ohio. The Fort Monmouth Crystal Laboratories (later located at Camp Coles and then at Long Branch, New Jersey) was active primarily in placing educational orders enabling manufacturers to obtain necessary priorities and get set up, in awarding Development Contracts on the design and development of equipment and to investigate technical problems, and in research work. The Laboratories also operated a Pilot Plant and for a brief period gave courses of instruction to new manufacturers. The present laboratory activity includes the development of all crystals used in ground force signal equipment. The Crystal Branch of the ARL, beginning in 1943, did valuable laboratory and field work and contributed to the increase in quality of both oscillator-plates and holders.

Special acknowledgement also should be made to the Bell Telephone Laboratories and the Western Electric Company, who contributed greatly to the success of the crystal program. These companies freely supplied invaluable technical information and led in the development of several types of manufacturing equipment, notably the drill press lap, immersion conoscope, inspection tank for raw quartz and *x*-ray methods for controlling orientation. The fundamental theory and design of oscillator-plates is largely owing to work carried on over many years at the Bell Telephone Laboratories. They developed low temperature coefficient crystals and associated electronic equipment, studied the modes of vibration of oscillator crystals and predimensioning, and developed wire suspension metal-plated crystals.

During 1942 and the early months of 1943 about 100 new manufacturers, in addition to a dozen or so older companies, were in the production field. Several received direct government financial aid. The Signal Corps furnished instruction to all plants needing it, and also equipped many plants. This industry, driven by insistent demands of the Armed Services for immediate and large production, from 1941 to the end of 1944 delivered roughly 55,000,000 quartz oscillator-plates. The total amount of raw quartz used to manufacture these crystals amounted to thousands of tons. In addition, probably half again as much quartz was partly or completely processed but was wasted or unusable due variously to ignorance, carelessness, haste and lack of adequate technical controls. The cost of tooling up and doing the job amounted to about a third of a billion dollars. Production still is continuing on a large scale. A tabulation of the principal types of oscillator-plates put into mass production from 1942 to date is given on the next page.

Some of the difficulties that had to be overcome in establishing the crystal industry may be mentioned. Great quantities of raw quartz crystals had to be supplied. This material was obtained entirely from Brazil, where the purchasing and initial grading was carried on under the direction of governmental agencies and private importers. A considerable effort also was made to extend and mechanize the primitive quartz mining and distributing industry in Brazil. A stockpile of some millions of pounds of quartz was built up in the United States by the Metals Reserve Corporation, the material being graded by the National Bureau of Standards, and this and privately imported quartz was allocated to industry by the Miscellaneous Minerals Section of the War Production Board. During 1942 the supply situation became acute due in part to difficulties of sea transport and considerable amounts of quartz were flown by plane from Brazil to the United States and even to England. Efforts by Government agencies and others to find or develop commercial supplies of raw quartz within the United States proved unsuccessful and only a few tons of domestic quartz, mostly from Arkansas, were processed. Unsuccessful attempts were made to synthesize large quartz crystals. The price of faced raw quartz crystals ranged from about $5 to $10 per pound for material of average quality and up to $30 and more with increasing size and perfection. Raw quartz crystals of average size and quality are shown in Fig. 2. One pound of quartz yielded on the average little more than a dozen BT-cut oscillator-plates. Unfaced quartz was relatively abundant and cheap but efforts made to equip and teach the industry to handle such material met with reluctance.

The problem of taking a prewar laboratory-scale quartz cutting industry and equipping it almost overnight on a mass production scale with modern precision tools was very great. For many types of equipment, especially lapping machines, *x*-ray goniometric apparatus and frequency measuring equipment, designs had to be created. Manufacturers were found or created to make the equipment and then supplied

TABLE 1. DELIVERY OF QUARTZ OSCILLATOR-PLATES FROM THE CRYSTAL INDUSTRY TO THE ARMED SERVICES, 1941–1945[1]

Type[3]	Remarks[2]	1941	1942	1943	1944	1945
FT-171-B	AT 1.5 to 6.0 mc. Freq. tol. = ±0.02%. Temp. range −40° to +70°C. Used in armored force, field troop and artillery command sets.		132,351	846,521	521,014	
FT-241-A	DT-cut, 200 Kc. CT-cut, 300 to 1200 Kc. Tol. = ±0.02%. Range −40° to +70°C. Tank and other ground vehicle radios; field artillery.		2,836,293	3,568,651	4,488,362	
FT-243	AT and BT 2.0 to 9.0 mc. Freq. tol. = ±0.02%. Range −40° to +70°C (varies). Walkie-talkie, handie-talkie, and other portable combat sets; field artillery sets.		2,104,712	9,711,967	11,000,469	
DC-8	AT and BT 4.3 to 9.0 mc. Range −30° to +50°C. Aircraft command sets.		122,681	370,702	141,552	
DC-9	AT 1000 Kc. 15 cycles at 20° and 60 cycles over −30° to +50°C; operative −40° to +70°C. Calibrator crystal in frequency meter.		33,979	117,655	28,520	
DC-11	BT 5 to 9 mc. Freq. tol. = ±0.02%. Range −55° to +90°C. (A grade) Aircraft radios.		214,370	1,860,499	536,802	
DC-20	BT 5.6 to 5.7 mc. Freq. tol. = ±0.02%. Range −40° to +85°C. Airforce; runway localizer.		34,561	235,751	32,745	
DC-26	BT 5 to 9 mc. Predecessor to CR-1. Aircraft radio.		—	787,755	5,139	
DC-34, DC-35	AT or BT 1.6 to 4.5 mc. Freq. tol. = ±0.02%. Range −40° to +70°C. Ground forces; vehicles.		—	42,941	1,770,999	
CR-1A/AR	BT 5 to 9 mc. Freq. tol. = ±0.02%. Range −55° to +90°C (A grade) Aircraft radios.		—	1,359,957	7,274,909	
Other[4]			372,525	1,260,215	2,783,474	
	Totals	100,000 (est.)	5,851,472	20,362,614	28,583,985	30,000,000 (est.)

[1] Figures furnished by the Signal Corps, include Lend-Lease shipments.
[2] Tolerances and temperature ranges are those currently used, and are considerably more stringent than those in effect on 1941, 1942 and most of 1943.
[3] FT numbers refer only to holders; DC and CR numbers refer to complete units.
[4] Includes Navy crystals, in part of above mentioned types.

with machine tools and other critical materials. A number of these operations were bolstered with high priorities and financed with Government funds from the Defense Supplies Corporation. The phrase "priming the pump" was popular in Washington at this time. Most of the equipment was held in Signal Corps pools and allocated to the industry. While not crystal manufacturers themselves, the Galvin Manufacturing Corporation of Chicago coordinated more than 30 subcontractors located over

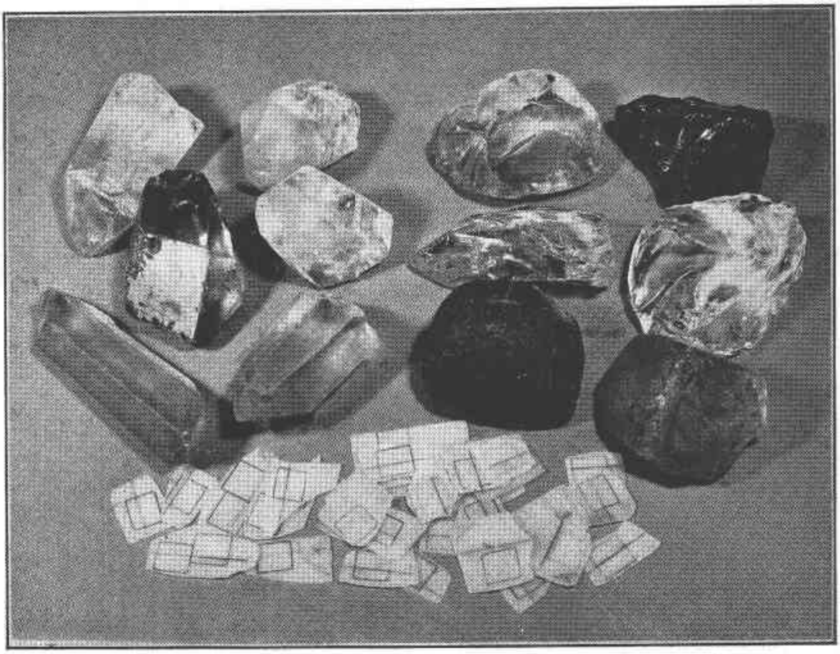

FIG. 2. Faced (left) and unfaced (right) masses of quartz of average size. The sawn wafers have 0.5×0.6 inch blanks marked out thereon.

the entire country who made crystals in holder type FT-243 for "walkie-talkie" and other ground radio equipment of their manufacture. Galvin formed several equipment pools to supplement those formed by the Government, the most important item covered being the Atlas drill press lap, and among other services issued a series of short mimeographed bulletins (62 to date) dealing mainly with practical matters in crystal manufacturing. The North American Philips X-Ray Co., Inc., and later the General Electric X-Ray Corp. undertook the design and manufacture of x-ray equipment to control cutting angles and together have delivered about 300 units to the industry. The Naval Research Laboratory, Anacostia Station, D. C., developed the sensitive Geiger counter and electronic circuit for the Philips unit.

A number of crystal manufacturers also made important contributions to the art. The Bliley Electric Co., Bell Telephone Laboratories and Harvey-Wells Communication, Inc., pioneered the etching-to-frequency method of finishing crystals.[1] The Bendix Radio Corporation of Baltimore cooperated with Signal Corps technicians in the development of crystal cutting procedures, developed the parallelogram light-figure method of orientation, and contributed to the design of both crystal lapping and *x*-ray orientation equipment. The G. C. Hunt Co. and P. R. Hoffman Co., both of Carlisle, Penna., developed the precision planetary lap. The milling method of finishing crystals was developed in the laboratory of the Galvin Manufacturing Co., Chicago. The North American Philips Co., Dobbs Ferry, N. Y., provided facilities for studying the orientation and cutting procedures described in a series of official Signal Corps publications, developed precision lapping and cutting equipment and methods in their Pilot Plant, and contributed in various ways to *x*-ray methods of orienting quartz. The North American Philips X-Ray Co. also designed and constructed equipment for the *x*-ray irradiation method of adjusting crystal frequency. The Reeves Sound Laboratories, Inc., of New York City, discovered and applied the *x*-ray irradiation technique of adjusting crystal frequency, developed safe etching compounds for quartz, and helped investigate the cause and cure of crystal ageing.

Among the principal difficulties confronting the newly established industry were uninformed management, the scarcity of skilled personnel, and the general lack of technical information, especially that dealing with the practicalities of orienting quartz and cutting plates therefrom. The prewar experience of many of the new manufacturers was in such fields as the manufacture of lamp shades, grindstones, transformers, neon lamps, sound recording apparatus and butchers' supplies. One was an undertaker. More than one of these new companies soon were producing more crystals in a week than the whole country did in the year 1939. Electronic engineers with or without a knowledge of quartz oscillator-plates, crystal physicists and crystallographers were hard to find and desperately sought. Many potentially useful men had already been drafted into the Armed Services. The Signal Corps did its best to help

[1] The method of etching quartz plates to frequency with hydrofluoric acid was patented (No. 1,869,160) in May, 1928, by W. A. Marrison of the Bell Telephone Laboratories.

this situation by field visits of staff technicians and by publication[2] of a series of mimeographed technical handbooks and bulletins written by members of the Quartz Crystal Coordination Section, Washington, and the Signal Corps Laboratories. Steps were taken, as in other critical industries, to prevent the drafting of key men. There was also a free and ready interchange of technical advice and assistance between the various manufacturers.

Technical difficulties also beset the new industry. The so-called Beilby-

[2] Publications of the Quartz Crystal Section, OCSigO, include:

Frondel, Clifford, and others, Handbook for the Manufacture of Quartz Oscillator-Plates, August 20, 1942.

The following six information bulletins were issued as supplements to the Handbook:

Waesche, Hugh H., Procedure for finishing quartz oscillators, Inf. Bull., No. 1, Sept. 25, 1942.

Waesche, Hugh H., Equipment used for quartz crystal finishing and testing, Inf. Bull., No. 2, Sept. 25, 1942.

Woods, E. K., Memorandums on ordering information, Inf. Bull., No. 3, Sept. 24, 1942.

Richmond, Wallace E., Technique of sawing quartz, Inf. Bull., No. 4, Oct. 12, 1942.

Waesche, Hugh H., and Wolfskill, John M., A method of orientation and sawing of small unfaced quartz, Inf. Bull., No. 5, March 1943.

Frondel, Clifford, Technical practices in the crystal industry of the United Kingdom, Inf. Bull., No. 5, 1943.

Parrish, William, and Gordon, Samuel G., Manual for the manufacture of quartz oscillator-blanks, February 15, 1943.

The following four papers were issued as supplements to this widely used Manual:

Parrish, William, and Gordon, Samuel G., Procedures for unfaced quartz and large quartz, Supp. No. 1, March 31, 1943.

Gordon, Samuel G., The inspection of quartz, Supp. No. 2. July 1, 1943.

Gordon, Samuel G., Salvage of quartz and reclamation of rejected crystals, Supp. No. 3, July 1, 1943.

Bottom, Virgil E., Procedures for etching crystals to frequency, Supp. No. 4, Aug. 1, 1944.

Publications of the Fort Monmouth (now Long Branch) Crystal Laboratories (Signal Corps Ground Signal Agency) comprise 21 articles to date, among which may be mentioned:

Technical News Bulletin #5, "Orientation Method for the Use of Small Unfaced Quartz," 1942.

Technical News Bulletin #7, "Limits of Usability of Raw Quartz," 1943.

Technical News Bulletin #9, "Procedure for Cleaning Crystal Blanks," September 1943.

Engineering Memo. #1, September 1943, "Recommended Procedure for Predimensioning Broad Frequency Tolerance AT and BT Oscillator-Plates."

Engineering Report #778, January 1943, "*X*-Ray Orientation of Small Unfaced Quartz."

Engineering Memo. #4, June 1944, "Ageing of Quartz Crystal Units."

Engineering Report #12, August 1943, "Small DC-9 Crystals."

Engineering Report #7, April 1943, "The Impedance of FT-243 Crystals."

layer, debated pro and con for many years, turned out to be an unfortunate reality that in 1943 nearly caused cessation of manufacture of high frequency crystals. It was found that millions of crystals held in storage in Signal Corps depots or issued to the Services had deteriorated to such extent as to make them unusable. The ageing phenomenon commonly appeared as a spontaneous increase in frequency with an accompanying partial or complete loss of "activity." The effect was traced to changes with time in a thin skin of misaligned and possibly hydrated quartz produced by abrasive action on the plate during manufacture. Etching in a solvent to remove this layer was found to obviate the effect. It was also found that corrosion and water absorption occurred to an objectionable degree in phenolic type crystal holders when used in the tropics, and this led to the use of improved plastics relatively impervious to moisture and to the accelerated development, still under way, of hermetically sealed glass or all-metal holders. Predimensioning became the subject of much concern. Predimensioned crystals are cut to certain rigidly specified predetermined physical dimensions that ensure satisfactory performance, but most manufacturers preferred for various reasons, especially in high frequency plates, to cut to arbitrary dimensions and hand tailor each crystal individually by edge lapping to give maximum performance. The Signal Corps exerted pressure on the industry to increase the efficiency and economy of manufacture and the quality of the product. Outstanding production records in certain plants and price renegotiation also acted to stimulate the industry in these regards. During 1943 special efforts were made to conserve quartz by improving cutting methods and reducing crystal size. The use of a proportion of unfaced quartz was made obligatory on most contracts. Increasing emphasis was placed on care in finishing the crystal, cleanliness and final inspection. In 1944, etching-to-frequency techniques were made mandatory, and the specifications of crystals with regard to temperature testing range and frequency and activity tolerances were further tightened. More recently, hermetically sealed holders are required for certain types of crystals in place of the older phenolic types. Price competition—largely lacking in preceding years of huge demand and small supply—is becoming marked.

The following Symposium of papers is primarily concerned with descriptions of the occurrence and characters of industrial quartz crystals and of the orientation methods used in manufacture. The principal manufacturing methods and tools also are described in some detail, but the electronic side of the field is touched only in passing. The manufacturing methods described are principally those used in the mass production of shear mode BT and AT plates.