



# History and Development of the E•A•R Foam Earplug

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## *About the Author*

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## ABSTRACT

What does one do with a new vinyl material that has exceptionally high energy absorption characteristics? Noise, vibration, and shock control come to mind. If the material can also be foamed and is safe for dermal contact, even broader applications could be anticipated. But, making it into a hearing protector – that’s a step that no one took seriously until Ross Gardner Jr., a chemist who drew on lessons learned through association with an acoustical consultant, decided to try making earplugs. His early work at National Research Corporation in the late 1960s, which he continued in the early 1970s after his research group was purchased by Cabot Corporation, led to the development of an exciting hearing protector, at that time, called the E•A•R™ foam earplug. This earplug, commercially introduced in 1972, which provides an exceptional combination of comfort and attenuation, rapidly became the world’s best-selling hearing protector, spawning numerous imitators and patent litigation in 10 countries. This paper describes the inception and development of this product as well as some of the concepts behind its success.



Ross Gardner Jr.

## INTRODUCTION

The story begins in the mid 1960s at the National Research Corporation. National Research, with a string of successful developments under its belt including the first commercial process for producing penicillin, the first instant coffee, and the first frozen orange juice, was purchased by Norton Co. The new Norton Research Corporation (NRC) expanded its investigative horizons with the creation of an innovative Materials Research Group under the leadership of one of their brightest scientists. The group, although small in numbers, worked on diverse projects such as encapsulation of exotic solid rocket propellants, polymerization of diamond, production of room-temperature superconductors, instant-cure lane-marking paint, and a new generation of joint sealants. The last of these initiatives, the joint-sealant project, which was amongst those assigned to a young chemist, the late Ross Gardner Jr., was the unlikely

genesis of what later came to be known as the E•A•R Classic foam earplug.

In 1967, while immersed in his work, Ross noticed that the joint sealants he was developing possessed unusual energy-absorbing properties. As a result, he asked for and was given the assignment of beginning work on an internal energy-absorbing-resins project, the name of which later became the basis for the acronym “E•A•R.” Ross developed a series of materials based upon epoxies, hybrid epoxy/vinyls, and vinyls (polyvinyl chloride). The first of the materials that found its way to the marketplace was a highly damped vinyl dubbed C1002, still successfully sold today by Aearo Technologies L.L.C., a 3M company.

The initial application of the material was in constrained-layer damping systems to control noise and vibration in the foundry industry. After a preliminary marketing study, the solid-vinyl version of the energy absorbing resin was also produced as a foam sheet material, and trial marketing was initiated.

In spite of its successes, or perhaps because of them, NRC was sold once again, this time to raise money for the parent company, Norton. The purchaser, another old New England firm, was Cabot Corporation, known primarily for its carbon blacks and specialty chemicals.

## A CONCEPT IS GERMINATED

Ross’s work continued and recognition of the E•A•R materials spread. Dr. Allen Mills, a professor at nearby Tufts University, learned of NRC’s work and approached Cabot with an idea for an earplug. Although the concept was later patented, it was never successfully manufactured nor

marketed. However, the meeting started Ross thinking about other applications for his E•A•R materials. Having recently been tutored by a sharp young acoustical consultant, the late Curt Holmer of Bolt Beranek and Newman Inc., Ross developed his own ideas about what might make a superior earplug. He reasoned that energy absorbing materials which act like a composite shock absorber/spring system on a molecular basis could be very soft statically but very stiff dynamically, especially to incoming sound waves.

Ross wanted to create earplugs from the solid C-1002 materials, but lacked suitable molds. So he set out to fabricate a set of earplugs by hand from sheet material. After a few futile attempts at hand fabrication, his next best idea was to cut earplugs from the foamed version of the blue material. If this showed promise, the subsequent step would be to purchase a mold to make earplugs as he had originally intended.

The foam itself was not expected to make a good earplug because of its low mass. After all, it was generally recognized that mass was important in creating a barrier to airborne sound. Although equations had been written to predict earplug attenuation, few realized or thought that such low-mass objects as foam earplugs could successfully block sound at the ear. In fact, to this day, the typical reaction of those unfamiliar with foam plugs is to be suspicious of the plug’s ability to provide a high degree of noise reduction.

Once the foam earplugs were fabricated into cylinders, it was quickly noted that they could be easily compressed for insertion into the ear. As the plugs expanded and began making a seal inside the ear canal, all of the noise within the laboratory started

to disappear, even the low-frequency noise produced by a laboratory hood. Ross was amazed!

He then began work in earnest. Cylindrical earplugs with various diameters, bored from foam of different densities, were evaluated. Competitive earplugs and data sheets were obtained, and a preliminary literature search conducted. Although the average equivalent diameter of ear canals was found to be about 3/8 inch, there was insufficient information on ear canal anatomy to make an informed decision on sizing. Ross fit earplugs to many co-workers and finally settled on cylinders having a diameter of 0.61 inches.

### SELLING HIS IDEA

As Ross began to try to convince others of the amazing performance of his comfortable self-fitting foam earplugs, the general reaction was “But they’re only little pieces of foam,” with the inference being that as such, they couldn’t be all that important. Finally, Ross was given a chance by NRC to solicit feedback from a select group of their distributors. With secrecy agreements in hand, Ross took a dozen men into a tiny conference room. He handed out foam earplugs and demonstrated their use. When he asked his audience to wear them, he met with considerable resistance and had to repeatedly coax them to get them all fitted.

The demonstration was short, simple, and effective. Ross spoke to them and ascertained that he could be heard. He then picked up a one-square-foot steel plate and pounded it with a hammer, while again inquiring whether he could be heard. They once more responded in the affirmative. While still pounding on the plate, he then asked them to take out their earplugs. Not suspecting how much noise the plugs were actually blocking

they complied, and then, no longer being protected from the fearsome racket, were quickly driven from their seats. They jammed in the doorway trying to exit the room as quickly as possible. It was only then that it was thought, “maybe he has something there.”

### PATENTING THE FOAM EARPLUG

Now it became clear that the new foam earplugs were potentially marketable, and in 1971 Cabot’s Director of Corporate Research, Dr. Charles Shoup, who had taken an interest in the project and who was later to become the first president and CEO of E•A•R Corporation, insisted that patent applications be filed in the United States and other countries.

The novel and unexpected aspects of the foam earplug were easy to substantiate, and patents were promptly drafted and successfully filed in the principal industrial countries of the world. A key claim of the patent read as follows:

An earplug having a size and shape adapted to be compressed and inserted into the human ear canal and there allowed to expand and obturate the ear canal, said earplug comprising a resilient plasticized polymeric foam having a sufficiently high concentration of organic plasticizer as to provide said foam with a rate of recovery from 60 percent compression thereof to 40 percent compression thereof of from 1 to 60 seconds and an equilibrium pressure at 40 percent compression thereof of from 0.2 to 1.3 p.s.i.<sup>1,2</sup>

Eventually patents were granted in the United States, Canada, most European countries, Russia, Japan, and Australia. The plugs were first sold in 1972, dedicated distribution

was set up in 1973 and full scale-production commenced in 1974, the same year in which the first US patent was issued. That patent was augmented with a reissue in 1977. By the time the United States and worldwide patents expired in the early 1990s, the little foam earplug had grown to pre-eminence in the hearing conservation market and the company it had launched was a worldwide leader in the industry.

### NOVEL AND UNEXPECTED

In order for an invention to be patentable, it must be new, novel and unexpected to one of ordinary skills in the art. Clearly, the new slow-recovery self-fitting foam earplugs met the requirements. In fact, as mentioned above, they were so unexpected in their effectiveness that it was often difficult to overcome people’s preconceived notions about them.

Even in the scientific community, the concept of foam was not discussed in the few available theoretical analyses of hearing protector capabilities which had been published in the peer-reviewed literature. For example, in one of the earliest and most significant contributions, the *Benox Report*, there is an electrical analog model presented of the earplug system and the physical constants that control its performance. The authors stated: “Only the length over which the earplug touches the skin lining, and the pressure with which the plug is inserted, should modify these constants. For most earplugs commonly used today these parameters do not change much.”<sup>3</sup>

In retrospect, it is clear that a foam earplug would modify the constants by changing the length over which the earplug touches the skin, and hence the effective shear compliance of the flesh, but at the time it was unmentioned and/or unsuspected.

About a decade later, in another theoretical treatise also based upon a lumped parameter model of the hearing-protected ear, the author wrote: “Since a tighter fit of ear plugs, although reducing the shear compliance of the lining against which the plug presses, is accompanied by considerable discomfort we may assume that we have very little control over the parameters in this equation. Hence the low-frequency attenuation of earplugs is in practice a fixed quantity for each individual.”<sup>4</sup>

Once again, the crux of the problem was identified, but the not-so-obvious solution of a foam plug was never suggested. In fact, with foam plugs, the low-frequency attenuation can be increased from typical values of 20–30 dB for non-foam earplugs in the frequency range from 125 Hz to 500 Hz, to values of 40 dB and greater.<sup>5</sup>

It wasn't until 1979, five years after the patent issued and a couple of years after the plug was on its way to becoming a success, that foam earplug performance was recognized and acknowledged in the professional acoustical literature. In that year, Edgar Shaw in a review paper on hearing protector attenuation wrote: “The performance of plug 4 is truly impressive. This is a foamed polymer plug which expands in a few seconds to make contact with a large area of the ear canal wall, thus forming a rigid airtight seal.”<sup>6</sup>

## EARLY PRODUCTION AND SALES

To say that the early E•A•R Corporation was sparsely funded would be no exaggeration. For example, initial production of the foam earplugs was effected with a 100-year old manually operated shoe press, which had to be purchased and refurbished under separate work

orders since the total cost would have exceeded Ross's signature authority. Co-workers and friends fabricated the earplugs before work, during lunch, and even after hours. Labelling and packaging was also accomplished at odd hours. In spite of the hand-to-mouth operation, Ross estimated that two million pairs of earplugs could be sold the first year (1972) through the NRC distributors. When the distributors themselves were polled as to their opinion, their independent estimates exactly confirmed Ross's own.

Nevertheless, a contract was drawn up ceding sole marketing rights to Marion Health and Safety Co., a major player in the safety market. Ross prevailed, however, in assuring that a clause in the contract would guarantee E•A•R Corporation the right to compete with Marion. An irony of the situation is that 10 years later, Marion was purchased by Norton Safety Products (later to become Siebe North), the company that owned NRC at the time of the genesis of the E•A•R project.

In spite of the marketing rights that E•A•R Corporation retained, they had no intention of aggressively selling foam earplugs under their own brand name. Initially Marion was quite active in selling the slow recovery foam earplugs under the trade name of Decidamp, but the sales soon diminished as Marion put emphasis on their Peacekeeper custom-molded earplugs. Those earplugs had been recently acquired from GE, a company that had spent a few million dollars advertising them on television.

With the slump in sales, Marion's purchases fell below the amount specified in the contract for them to retain exclusivity. Dr. Shoup then made the decision to give the go ahead to Arthur Lagace, program

director, and Tom Sweeney, marketing manager, to set up a distribution network for the direct sales of E•A•R foam earplugs (today referred to as the E•A•R Classic foam earplugs).

## THE “TRADEMARKED” PACKAGE

Not only were the foam earplugs a new concept to the marketplace, but they were also difficult to promote because of their unprepossessing nature. Presentation and packaging were crucial to success. A project was initiated to select an appropriate package. The criteria were that the package had to be unique, economical (costing less than one cent), and reusable so that it could provide short-term storage for the earplugs. The now-familiar paperboard pillow pack was the outcome of this effort and is still widely used today.

Because of the distinctive characteristics of the pillow pack, filling it with earplugs required a specially engineered and costly piece of equipment, which the small company could not then justify. Thus, for the first five years of full-scale production, all packaging was done by hand. After soliciting several quotes, E•A•R Corporation found the best price to be provided by Dew Lane Associates, a small group mainly composed of housewives, managed by the marketing manager's wife, Sue Sweeney. At its peak, Dew Lane employed 100 or so packagers. Each packager had to set aside a room in her or his house, to be kept clean, free of food and the like, and open to inspection upon request. Packagers also signed a statement that they understood the use of the product they were handling, and would amongst other things, clean their hands before packaging any earplugs.



## EARLY TESTIMONIALS AND PRODUCT MODIFICATIONS

Early in its history the E•A•R Plug was recognized for its excellence in design, when *Industrial Research* magazine designated it, in 1972, as one of the 100 most significant new technical products of the year.

One of the initial independent attenuation studies conducted on the E•A•R Plugs was a comparative real-ear attenuation test by Robert Camp, Jr., Ben Mozo, and others at the US Army Aeromedical Research Laboratory at Fort Rucker, Alabama.<sup>7</sup> They had set up a percentile ranking system based upon 64 hearing protectors they evaluated, with the results summarized using the Attenuation Efficiency Score (AES). When they completed evaluation of the E•A•R Plug, they found it surpassed all of the devices they had previously tested.

Unfortunately, this alone was insufficient to assure military approvals. Key officers had to be approached and convinced of the merits of the product. One officer could not fit the E•A•R Plug. Ross and Tom quickly flew out to find out what was the matter. It turned out to be a combination of an extra-small ear canal and a rolling technique in which the officer was too leisurely in getting the compressed plug from his hand into his ear. What to do?

Because of course this was not the only complaint that had been received, simply the most prominent, an optimization project was begun. The project was directed at slowing down the recovery rate of the foam and producing the earplug in a smaller size. Central Michigan University was commissioned to conduct a study in which the ease of insertion, comfort and attenuation of two smaller plugs (0.50" and 0.54") and the original

0.61" diameter plug were compared. The 0.54" diameter size was selected, and to this day has proven to be the best choice in a one-size-fits-most product.

Not only has the 0.54" size been retained, but so too has the 1974 foam formulation, which has been shown to be stable and effective for over 30 years. In fact, some initial production plugs from 1974, Lot 04 are retained in the 3M E•A•RCAL Laboratory and still found to perform within specifications (circa 2009), as do the laboratory's control lot of plugs which were fabricated in 1979.

## PROVIDING MORE THAN JUST AN EARPLUG

Ross, whose entire background was in research and development, believed that a revolutionary product should be presented to the technical community as well as to customers and that this should include a training program as well as other support activities.

In 1976, the author, an acoustical engineer just-graduated from North Carolina State University, was hired to work primarily with the noise control materials and to develop applications and support for those products. Although he worked diligently as assigned, his interests kept drawing him towards the foam earplugs and the myriad unanswered questions inherent in the design, performance, measurement, and application of that simple little product.

With the whole-hearted support of both Ross and the entire young company, the author was directed to develop for E•A•R Corporation all of the capabilities and technical support services that would be expected of a world-class manufacturer of a top-quality hearing protector. This included educational materials and seminars (see next section), peer-reviewed pub-

lications, a well-regarded acoustical research laboratory, and strong participation in national and international standardization and professional associations and committees.

## WHY WAS THE E•A•R PLUG SO SUCCESSFUL?

The key to the product's success was its combination of highest attenuation, best comfort, low price, a one-size design, and the effectiveness with which this information was transmitted to the market place. Sales were also aided by fortuitous government regulations, namely the advent in 1971 of the Occupational Safety and Health Act and the associated noise standard,<sup>8</sup> followed some 12 years later by the hearing conservation amendment.<sup>9</sup>

An important aspect of the marketing strategy was the recognition that the most effective and economical method of convincing potential customers of the merits of an unassuming new product with unexpected performance advantages, was to get it in the hands of the end users so they could give it a "test drive." Thus, E•A•R Corporation implemented a liberal sampling policy. Generous samples of earplugs would be supplied to a safety director who would in turn give the earplugs to employees with whom they were having difficulty enforcing the wearing of current protectors. Because of the comfort of the E•A•R Plugs, it was usually quite easy to get employees of all types to wear them.

The remaining aspect of the success story was the broad range of peripheral services offered by E•A•R Corporation. Selling hearing protectors involves three customer groups; the distributor, the approving body, and the user. The distributor was supported by same-day shipments, high-quality advertising programs (see

examples in Figures 1–3), full-day end-user clinics (called “E•A•R Clinics”), and educational/training materials such as the highly acclaimed technical monographs dubbed the EARLog Series, first published in 1979, and 21 issues later, still appearing today. The approving body was supported by having a one-sized product which was effective enough to protect against virtually all occupational noise exposures, combined with support materials such as posters, films, and the other literature mentioned above. The final user, of course, was sold on the comfort of the E•A•R foam earplug, as well as in most instances the high degree of delivered protection.

## VINYL vs. URETHANE, AND THE EARLY IMITATORS

Although the E•A•R Plug was manufactured from a slow-recovery foam, other materials such as urethanes can be used as well. Ross had selected vinyl because it was the material with which he had been working when the idea of an earplug first occurred to him. As it turns out, vinyl has proven to be one of the best materials to use for this application.

Early imitators, and those in the marketplace today, more often chose polyurethane as the material of construction for their earplugs. In part this was because a number of companies in the foam business with existing in-house expertise in slow recovery urethane foams saw the success of the vinyl-foam E•A•R Plug and were looking for applications for their own foam materials. They sold their technology, usually in the form of raw materials, to the other companies who produced and marketed the imitation products.

An advantage of the polyurethanes is that they are easier to mold into a shape than are vinyls. This provides



Figure 1.



Figure 2.



Figure 3.

substantial cosmetic advantages, but the preponderance of technical data do not demonstrate any performance advantages of molded shaped foam plugs. To the contrary, unless one is very careful in the selection of shape, plugs may be produced (for example having too severe of a taper) which do not seal as wide a range of ear canal sizes as can be accomplished with a cylindrical foam earplug.

Another feature of urethanes is their “hand” or softness, which is quite pleasing, but in the ear canal has little actual effect on comfort. Furthermore, in designing an optimized foam earplug it is crucial to balance the need for sufficient stiffness so that the plug can be easily inserted and negotiate the bends in an ear canal without folding, squashing, or creasing, with the requirement for sufficient softness to provide good comfort. Experience has shown that the characteristics of Ross’s initial vinyl foam appear to be nearly the ideal compromise.

Disadvantages of polyurethane materials for use as foam earplugs revolve primarily around their stability. Their properties may change with absorption of moisture, or due to long-term hydrolysis in the presence of moisture and light. Also, most polyurethanes are more flammable than their vinyl counterparts. Of these

shortcomings, the principal problem area revolves around water absorption and its effect on recovery characteristics. In high humidity, the recovery (expansion) times of most urethane earplugs become too rapid, making them difficult to properly insert and wear.

## E•A•R PLUGS HAVE BECOME “THE STANDARD”

In many ways, E•A•R Plugs have indeed lived up to the claims of the company’s early advertising campaign in which the product was positioned as “The Standard” against which other products should be judged (see Figure 3). Indeed, since the E•A•R Plug’s introduction, it has been tested in over 30 laboratories worldwide. The results of nearly 100 10-subject in-house tests, and an additional 140 tests conducted by independent laboratories are on file in the E•A•RCAL Laboratory database. Even in real-world studies, there is no product more thoroughly tested – a dozen studies in five countries with over 600 subjects.

In research publications as well, whenever a study is conducted that examines hearing protector performance or that utilizes earplugs to facilitate the investigation, it is likely that E•A•R Plugs will be the plug of choice. Over 100 publications have

documented use of the plugs in this manner.

Myriad unusual applications for the foam earplug have also been discovered by the company's customers and others.<sup>10</sup> They range from the mundane earplugs-as-solution to the snoring spouse ("Dear E•A•R: Your earplugs saved my marriage ..."), to the less commonplace such as preventing water from entering the ear canal during flotation in sensory deprivation tanks (where the person lies supine in body-temperature salt water); from the unique, such as noise-protection for a group of spelunkers exploring the world's largest, and incredibly noisy underground river (in the Nare cave on the Pacific island of New Britain), to the intense, where physicians use them to block the screams of children during difficult procedures in hospital emergency rooms; from animal research into the effects of noise where E•A•R Plugs have been fabricated for gerbils and sheep and other mammals, to routine animal use for show and competition horses to reduce their skittishness around crowd noise. Applications abound, limited only by the imagination of the user.

Awards and recognition continue to accrue for the E•A•R Plug, such as inclusion in the Museum of Modern Art's 2004 exhibition entitled "Humble Masterpieces," that features nearly 120 simple objects, from Post-It notes, to paper clips, M&Ms, and the Frisbee disk. (<http://www.moma.org/exhibitions/2004/humble.html>).

## THE E•A•R PLUG IN THE 2000s

During the years since the 1970s the company manufacturing the E•A•R Plug grew and its relationship to its parent company, Cabot Corporation changed as did the name and business description of the division. In April 1990, the E•A•R Division of Cabot Corporation and the safety products division of American Optical Corporation merged to form a new company, the Cabot Safety Corporation, which later changed its name to Aearo Company (known as Aearo Technologies). Then, in 2008, 3M purchased Aearo Technologies. Since then, "E•A•R" continues to be used as a brand name for certain products manufactured by 3M, but no longer is used as the name of the business entity that manufactures and markets hearing protection products.

Still today a few members of the early E•A•R Division, including the author, are associated with the 3M's research and development group responsible for E•A•R products, and through the years created additional well-known products including the world's first corded foam earplug (the E•A•R Plug with cord), the Caboflex™ Model 600 semiaural hearing protector, the UltraFit™ premolded three-flange earplug, the new category of pod plugs such as the PushIns™ earplugs, and the ER-20 Hi-Fi™ earplug that provides flat and moderate attenuation. 3M continues striving to develop products that are safe, comfortable, protective, and easy to use, and to search for the new and exciting E•A•R Plug success stories.

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