

# The beer barrel as a VHF cavity *resonator*

*In the 1970s, use of mobile radio frequencies was expanding dramatically and existing antennas were becoming heavily overloaded. The engineering solution devised by Gerald David was to introduce multiple transmitter combiners onto a single antenna using band-pass filters. The use of a beer barrel in this context shows how existing structures can be adapted to new uses at a fraction of the cost of purposely designed components.*



In the early 1970s, it became urgent to rationalise the numbers of antennas on radio sites as mobile radio had expanded dramatically, together with paging services, broadcasting and Home Office requirements. There had been a degree of site sharing even in the 1960s but there was a general feeling of suspicion in the security and government services about allowing commercial installations onto radio sites that were providing public or national security services. In many cases the well positioned high sites across the country had masts that were severely overloaded and the then current proportion of one transmitter to one antenna meant, in many cases, that additional services could not be accommodated.

Aerial Facilities Limited was set up to tackle this very problem through the use of band-pass filters. These were to be used in conjunction with critical

coupling harnesses to provide a 50  $\Omega$  network connecting several transmitters to one antenna while providing sufficient isolation between each transmitter so that no mixing occurred. It was also critical that there was very little power loss.

This technology could also be coupled with the use of very large low-loss feeder cables, whereas the previous technique used cheaper, braided, flexible cables with quite considerable losses, e.g. 3 dB at 150 MHz per 100 m run. The proposed cables would have solid inner and outer conductors of much greater size with a loss of 0.3 dB per 100 m.

The search was now on for resonant structures which could provide an unloaded  $Q_0$  of approximately 10 000 and were robust, long-lasting, easy to adjust and physically stable with temperature. The design had to be easily understood by installation engineers in order that the process of commissioning such a system would be straightforward and not an erudite exercise.

I spent many happy hours delving through the chemical, pharmaceutical,

beverage and finally the brewing industries before arriving at a fortuitous compromise of structure, conductivity and practicality. This turned out to be the 11 gallon IEC Worthington keg which was manufactured to very high mechanical standards and in very large quantities at a price which made any purpose-built structure quite out of the question. The end product had to be compared with the alternative price, i.e. of a single folded dipole and its associated braided feeder cable.

The budget price per transmitter combiner worked out at approximately £400, with the additional benefits of reducing interference and taking load off the mast, and the marketing price offered was £500. This meant that the cavity price, finished and ready to tune, had to be less than £250, since the remainder of the cost had to include the critical harness, the rack, the feeder cable and antenna. The commission, therefore, was to connect 10 VHF transmitters to one antenna

and thus break all the price barriers of the alternative, simpler system that was causing all the site problems.

### The barrel structure

The standard production barrel was a combination of cast sections welded together by an extremely hi-tech automatic welding process which produced seams that were almost invisible to the naked eye. The material used was generally aluminium LM25A or B and this was high conductivity, low corrosion, microscopically clean and free from imperfections such as casting faults. Throughout the whole life of development and implementation of this programme we did not come across any significant problems due to the casting or welding so the quality of the conductivity was of the highest order. The other great advantage of this device was the price which, in the raw form, was £47 per barrel when ordered in quantities of 100.

The preparation of the barrel involved cutting holes in the top surface to accommodate the centre conductor and the coupling loops. Figure 1 illustrates the basic barrel and Figure 2 shows the openings, tapped holes and aperture arrangements for the centre conductor and coupling loops. Following the piercing and

tapping process, the barrel was then immersed in a clear sealing fluid which was particularly relevant to the inside surface in order to prevent spurious oxidation due to trapped swarf, moisture etc. This was followed by an external painting process, which was done with the critical apertures and conductive faces masked.

The weight, rigidity and general physical structure of the barrel made it highly durable and free from instability due to mechanical flexing. There was, however, the temperature expansion coefficient which will be dealt with in the next section.

### The resonator characteristics

The concept of using the beer barrel was based on having a simple quarter-wave resonant structure centrally placed at one end, leaving the other end closed. The frequency characteristics were determined by the length of the centre conductor. The coupling in and out of the transmitter frequency was achieved with circular loops which simply fed the centre point of the connector directly to the loop and thence to ground via the body of the cavity. These loops were made of

16 gauge copper wire and silver plated, as was the connector assembly and these were lightly greased with a silver conductive grease in order to ensure a good non-oxidising junction. One loop was fixed and the other was allowed to rotate by means of a disc of silver-plated brass above and below the mating contact with the barrel. This allowed minute adjustment of the coupling impedance in order to match different transmitters; it was often difficult to match these to 50  $\Omega$ . However, by this means there was an infinitely variable match that would associate with cable lengths and could cater for a wide variety of transmitters and peculiar match combinations.

It was important at every stage to consider that this device had to be presentable to any site and compatible with any transmitter so a considerable degree of adaptability was required. Modifications could be carried out on site, i.e. to size coupling loops and angle, which was a very simple process, so there was no purpose in taking cavities back to the factory and thus spoiling the carefully timed programme of work on site.

External painting of the cavity also ensured a good insulation value from the mounting rack, thus reducing to minimum circulating currents that are always prevalent on radio sites and can cause intermodulation interference at the point of contact between different modules.

The first frequency band to be tackled was the 150–165 MHz base station band for mobile radio, which included a wide variety of users, including health authorities, security companies and transport organisations. The parameters that

**Figure 1** A basic barrel, specifically an 11 gallon IEC Worthington keg. The barrel has been manufactured to high mechanical standards

**Figure 2** The openings, tapped holes and aperture arrangements for the centre conductor and coupling loops



were sought were a transmission loss in the cavity of approximately 1.0 dB with isolation at 500 KHz away from the carrier not less than 25 dB. In practice, many installations had transmitters at less than this spacing, and at 250 kHz and below, two resonators would be coupled in series, thus doubling the isolation.

The unloaded  $Q_0$  obtained in practice at 150 MHz exceeded 9000 and in very carefully prepared cavities figures up to 9700 could be obtained. As the frequency of resonance was increased the  $Q_0$  increased correspondingly and was still perfectly satisfactory up to 175 MHz with the same centre conductor assembly as shown in the general assembly (Figure 3) and in detail in subsequent sections.

### The centre conductor assembly

The proposal to use the beer barrel as a resonator always included the intention to cover as many frequency bands as possible and the lowest frequency encountered in practice for mobile radio base stations was 68 MHz. Since the first production units were centred on the 150–165 MHz band their centre conductors were arranged to achieve lengths between 28 and 50 cm by means of extendable concentric tubes made in copper then silver-plated and connected to a brass top plate, which was also silver-plated. The interface connection, where the sliding joint was constructed on a silver-plated phosphor bronze fingering section, was brazed to the outer-centre conductor, thus allowing the inner-centre conductor to slide freely up and down and allow adjustment to the resonance frequency.

We must now consider the temperature coefficient; while the basic beer barrel is made of aluminium, the centre conductor assembly is made from brass and copper, so the temperature coefficients of these

components are very different. The air space between the bottom of the centre conductor at resonance and the bottom of the barrel would normally be arranged to exceed one-eighth of a wavelength and thus diminish the temperature coefficient effect due to the barrel. The temperature compensating element was an invar rod which was connected to the bottom of the inner conductor and passed through a collar at the top of the rigid outer assembly.

The upper boss was provided with a fine-thread, centre-adjusting inner boss which could be locked by grub screw to the invar rod, thus providing coarse adjustment by unlocking the grub screw and fine adjustment by rotating the threaded collar. This provided a solution for frequencies where the inner-centre conductor did not come within approximately one-tenth of a wavelength from the bottom of the barrel.

However, for frequencies which could be tuned but caused the centre conductor to come very close to the bottom of the barrel, different problems arose; i.e. the temperature coefficient became very complex and the stability both with temperature and power also became highly complex. The solution to extend the lower frequencies of operation was to envelop the bottom of the centre conductor with an outer concentric tube which, for convenience, was called a 'capacitor end section'. This provided capacitive loading of the end of the centre conductor, severely reducing the resonance frequency and eliminating the problems of proximity to the lower end of the barrel.

**Figure 3** The general assembly of the barrel, externally painted to seal the material and insulate the cavity. The centre conductor is also in place

**Figure 4** The centre conductor assembly – an extendable arrangement of silver plated concentric copper tubes connected to a silver plated brass top plate

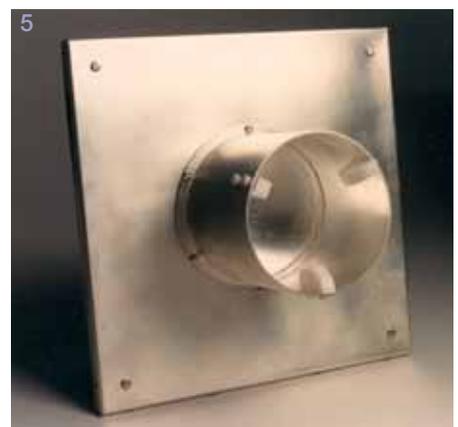
**Figure 5** The capacitor end section. This provides capacitive loading of the end of the centre conductor, thus reducing the resonance frequency and eliminating the problems of proximity to the lower end of the barrel



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This alteration by definition lowered the  $Q_0$  because of occupation of what was previously an air space. The benefits were, of course, considerable expansion of the range of operation and flexibility of use in that the same barrel could now be used from 67–175 MHz. The centre conductor assembly for these modifications is shown in Figure 4 and the detail of the end capacitive section is shown in Figure 5.

A great deal of experimentation was carried out in terms of temperature compensation using the capacitor end section and the best compromise was reached with a combination of invar, brass and steel where the steel portion occupied one-quarter of the length of the centre rod and the brass roughly a quarter, whilst the remainder was left as invar. This complex mixture gave a temperature coefficient of less than 0.5 parts per million per degree centigrade but held only over a narrow frequency band, i.e.  $\pm 5\%$  of the centre frequency. However, once the mixture was established, a table was produced showing the various combinations of materials for various bands and these held true over many years' production of these devices.

## UHF bands

The success of the barrel resonator in VHF bands led to its use being required for Band III, i.e. 174–224 MHz, and this was achieved simply by shortening the centre conductor by 25% thus allowing it to resonate over the required frequency range. There was a very rapid expansion in the use of UHF bands 420–470 MHz during the early 1970s and a resonator was required to cater for these frequencies. The standard barrel was then provided with a short centre conductor in the range 13–18 cm and this covered the band 430–470 MHz with a correspondingly higher  $Q_0$  and was able to cater for transmitter frequency suppressions as small as 300 kHz at 450 MHz. This centre conductor assembly is shown in Figure 6. It should be noted that the size of the coupling loop determined the basic insertion loss but, of course, increasing the size also reduced the loaded  $Q$  and thus a compromise had to be achieved in each case, with a trade-off between resonant frequency, insertion loss and isolation between transmitters.

## Frequencies above 470 MHz

There were many applications requiring resonators at frequencies above the commercial mobile radio bands and up to and including television frequencies; however, it was found that at about 590 MHz a horizontal resonance occurred in the field across the top face of the barrel, i.e. between the coupling loops and the side wall. This produced a spurious resonance which seriously damaged the performance and reduced the practicality of use of the standard beer barrel at these frequencies.

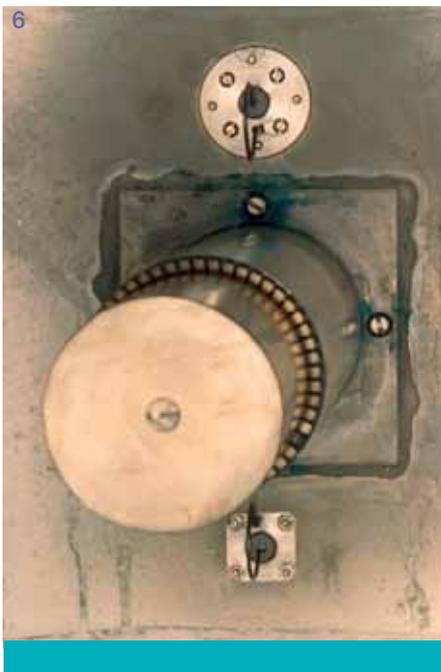
**Figure 6**  
The short centre conductor (13–18 cm long) used to cover the 430–470 MHz frequency range

## The VHF cavity resonator

This is best likened to an organ pipe which resonates at a frequency determined by its length. The note that one hears is that produced by the particular length of pipe and this is the only frequency that pipe will pass. This is exactly what happens in the VHF barrel cavity resonator in that, by the determination of the length, a resonant part of the barrel will pass only a particular frequency. It is, therefore, an excellent component from which to construct a network of resonators (a VHF multi-coupler) of which each component resonator passes only its own frequency.

## The need for high quality resonators

The difficulty that arose with the limited number of spaces for antennas on existing masts and the need to minimise the construction of new masts led to the introduction of multicouplers, i.e. systems that enable several transmitters and receivers to be connected to one antenna. The devices that enable this to be carried out simply are the resonator and cavity resonator. In this case a beer barrel is eminently suitable for the purpose.



**Figure 7**  
A modified square cavity used to produce operational resonators for the range 300–790 MHz

### Q-Factor

This is a measure of the quality of a resonator in terms of a tuned circuit. The quality number is determined by dividing  $Z$ , the dynamic impedance, by the DC resistance of the component in the simplest terms, i.e.  $Q = Z/R$ . If  $Z$  can be made very large and  $R$  made very small then the  $Q$ -Factor itself becomes large, leading to high efficiency.

It can be seen that superconductivity of  $R$  would give such a device an infinitely higher  $Q$  and it would be eminently successful as a filter. Superconductivity has been explored for these purposes although achieving the very low temperatures required is tedious and complex and, as yet, the engineering has not been mastered to a sufficiently practical or economical degree.

### The VHF mobile radio frequency band

This is the part of the radio spectrum immediately above VHF broadcast and immediately below the bottom end of the UHF television frequency band, i.e. it is in the 150–470 MHz range. These frequency bands have traditionally been used for mobile radio, and by the police, fire and ambulance services and the military, since the 1950s.



**Figure 8** Commercial use of beer barrel resonators at an airport. This system uses two antennas supplying ten and eight channels respectively

It was therefore decided that a square cavity of 150 cubic centimetres should be produced and this provided an operational resonator at frequencies above 300 MHz and up to 790 MHz, where it was also limited by transverse resonance producing deterioration in the end length resonance. This modified square cavity is shown in Figure 7.

### Practical applications

The main use of the beer barrel has been at VHF and a very good example of a large commercial installation is shown in Figure 8. This commercial airport has 10 channels of VHF connected to one antenna and on the standby system eight channels connected to the second antenna, which is located slightly lower on the mast, thus producing a less exposed position to lightning and storm damage.

The frequencies in this installation vary between 118 and 129 MHz and are critical for the operation of the airport. The particular installation shown in Figure 8 was installed in 1987 and is still in service, having given no problems and only requiring readjustment when transmitter frequencies need to be altered for operational reasons. On commercial sites in London the maximum number of transmitters coupled to one antenna was 27 and this was also in the 163–168 MHz frequency band.

There are currently many thousands of these resonators in commercial use throughout the world and they are still currently available, although the barrel has no practical use in the cellular frequencies due to the spurious resonance.

Smaller cavities scaled down in size, both circular and square, have been made but they still produce a similar  $Q$ , proportional to the frequency of resonance. Since these mechanical structures are both rigid and long lasting they provide a very dependable component in the RF system on radio sites and have mean time between

failures amounting to 50 years or more.

The beer barrel provides very good lightning protection since the input and output coupling loops are straight to earth, and unless the lightning strike is of such a magnitude that it will damage feeder cables then little or no damage results from a moderate strike and the radio equipment is not in any way affected.

There were many stories circulating in the industry regarding the need to empty the beer barrels before use and it is rumoured that several now well-known radio engineers came to work at Aerial Facilities due to the prospect of having to assist in emptying the barrels.

The impact of Bradford University on the research into performance of the barrel, its temperature coefficient and the emptying of barrels generally must be attributed by the writer since the success of the barrel was greatly hastened by the Bradford influence. ■

*Gerald David is Chairman and majority shareholder in Aerial Facilities Limited, designers and manufacturers of RF hardware, particularly combiners and filters, low noise amplifiers and cell enhancers. He formed the company in 1972 and built it up over the years to become Aerial Group; he sold the sites operation in 2000 and this is now part of Gridcom.*

*His career commenced at Standard Telephones and Cables and after four years at sea he returned to work at Airmec in High Wycombe, followed by Air Tech at Haddenham and then his own company, Aerial Facilities Limited.*

*He is very active in the Royal Academy of Engineering and the IEE and is Chairman of the ETSI committee, ERM TG 27 Radio Site Engineering.*

