IN YOUR WORKSHOP

As always occurs at August, Smithy the Serviceman, accompanied by his able assistant, Dick, leaves the familiar surroundings of the Workshop to sample life in the Great Outside World. Even the interruptions inevitable in this extramural scene do not, however, prevent the pair from discussing 50 c/s hum and public address line voltage working techniques

"I BEG YOUR PARDON?"

"I asked," repeated Dick, idly rolling over to present his back to the hot August sun, "what would happen if I were to touch the input grid of an a.f. amplifier down here on the beach?"

Smithy propped himself up on one elbow and stared incredulously at his supine assistant.

"Am I really to understand," he queried disbelievingly, "that you've dragged me all the way down to the seashore to talk about sticking your finger on an a.f. grid?"

Dick lazily rested his head on his arms in order to return Smithy's gaze.

"It was," he remarked casually, "just a thought."

Smithy turned away in disgust and, shading his eyes, scanned his surroundings. The yellow strand of sand was starting to fill up with its usual afternoon crowd of holiday-makers, each family arriving complete with a bag, its mysterious contents shrouded under a gaily coloured towel, a transistor radio, and assorted progeny. Already the surf was being kicked up by shrieking children, whilst their elders battled grimly with the waves farther out. Smithy and Dick had previously selected a stretch of sand which was relatively free of discharged oil, ice cream wrappers and orange peel, and had solemnly divested themselves of their outer garments to emerge in what each considered to be the optimum in beach attire. Dick wore snappy fawn trunks, whilst Smithy was resplendent in a pair of vast and flappy blue bathing shorts which had occasioned considerable ribaldry on the part of his assistant. Such ribaldry had, of course, been sternly suppressed by the Serviceman who, carefully placing the bag he had been carrying down on the sand beside him, had proceeded to stretch himself out on the sand. Dick had followed suit and the pair had allowed almost half an hour to pass in relative silence, the latter being broken only by a session of pop records on the Light Programme from a nearby radio.

Audible and Inaudible Hum

After Dick's last statement the silence returned, but it was clear that something was troubling Smithy.

"Why on earth," he grumbled, after several minutes, "should you ask me a question like that?"

"It's obvious," replied Dick immediately. "There's no mains wiring down here."

Smithy sighed. It was manifest that this would have to be pursued right through to the bitter end.

"Well?"

"If I touch the input grid of an a.f. amplifier in the Workshop," said Dick brightly, "I get a hum from the loudspeaker. What would I get down here?"

Despite himself, Smithy was becoming interested.

"I would suggest," he remarked, "that you would hear a 'plop' when you put your finger on the grid and another 'plop' when you took it off again. I'm assuming, of course, that the a.f. amplifier is a battery-driven job."

"No hum?"

"No hum," confirmed Smithy. "When you touch an a.f. grid your whole body picks up any electrostatic fields which may exist in the vicinity. And there shouldn't be any 50 c/s fields down here. It's possible, by the way, that if the battery-driven amplifier we're talking about had its h.t. supply derived from a vibrator or a motor-generator, you might hear some 'hash' from these. I'm assuming, incidentally, that there's no serious non-linearity in the early stages of the amplifier."

"What," asked Dick, "would happen then?"

"You might hear the local medium or long wave station," replied Smithy, "if the signal were strong enough. It would be detected due to the non-linearity in the amplifier."

"I see," mused Dick thoughtfully. "Getting back to the hum business, I've always thought it a pity that the mains frequency in this country is 50 c/s."

"Why's that?" queried Smithy.

"Well," continued Dick, "if it were a lower frequency it would fall outside the audible range and we wouldn't have to spend half as much time filtering it out as we do at present. Its frequency would be too low to be audible anyway!"

Smithy grinned.

"Apart from anything else," he chuckled, "a lower mains frequency would result in an increased national expenditure, if only because of the larger transformers that would be required whenever a change in voltage was needed. But you are, in any case, barking up the wrong tree. When it is reproduced over most of the radio and TV equipment which is in use today, a 50 c/s tone appears at quite a low level."

"Come off it, Smithy," said Dick indignantly. "I've heard enough 50 c/s hum from faulty radios and things like that to convince me that it's at a jolly *high* level. Dash it all, it's nearly deafening when you've got a serious fault."

"What you've been hearing," replied Smithy, "are, mainly, the harmonics of 50 c/s. For instance, you're pretty certain to hear a good loud hum if a smoothing capacitor in, say, a mains radio goes open-circuit. If the set has a full-wave or a bridge rectifier you then get a 100 c/s ripple on the h.t. line, which finds its way to the speaker via the a.f. stages. (Fig. 1 (*a*).) This ripple is far from being a sine wave and so it contains quite a few harmonics of 100 c/s as well as the basic 100 c/s note. The result is a good rich tone, which we refer to as a hum."

"What about half-wave rectifiers?" asked Dick. "The ripple from these is basically 50 c/s." (Fig. 1 (*b*).)

"True enough," agreed Smithy. "But it is so far removed from a true sine wave that it is, once again, full of harmonics. And so you hear 100 c/s plus a series of further harmonics of 50 c/s. Again, you get a full rich tone."

"Are you saying that I've *never* heard a 50 c/s tone?"

"Indeed I'm not," replied Smithy. "I was very careful not to be as dogmatic as that. The point I'm trying to make is that, with the usual small speaker and cabinet you encounter with radio and TV sets, a pure 50 c/s tone is not reproduced at by any means as high a level as the frequencies above it. This, combined with the falling-off in response of the ear at this frequency, can result in a 50 c/s tone being much less audible than higher frequency tones of similar amplitude. If you feed a pure 50 c/s tone from a good quality amplifier into a typical radio or TV speaker, you can often *feel*, by touching your fingers against the cone, quite a large amount of cone displacement for what appears to be a very low level of sound."

"What happens," asked Dick, "if you feed the 50 c/s output of your amplifier into a hi-fi loudspeaker fitted in a proper enclosure?"

"In that case," said Smithy, "the speaker *would* pump out a strong sound at 50 c/s. The amount of 50 c/s sound you actually *hear*, however, depends on the response of your own particular ear at that frequency. You will almost certainly find that you need to feed a signal with significantly higher amplitude into the speaker to reproduce a 50 c/s sound having the same apparent loudness as one at 100 c/s."

"Well, I'm dashed," said Dick. "It seems that, over the years, I've been listening to what I thought was a 50 c/s sound when, in actual fact, it was a 100 c/s sound together with harmonics."

"It *is* a little surprising," agreed Smithy. "The first time I bumped into the effect myself was quite a few years ago, when I was working on some high quality public address amplifiers intended for 100 volt line working."

Line Matching

Dick's eyebrows shot up.

"100 volt line working?" he asked. "What's that?"

But Smithy had lost interest in matters technical and was delving into the bag alongside him. Eventually he produced a large black cylinder fitted with a nickel-plated handle at the top.

"What," he remarked proudly, "about this, then?"

Dick tore his mind away from the mysteries of Smithy's previous statement and examined the object.

"What is it?"

"This," said Smithy, placing the cylinder on the sand and unfastening two small clips at the top, "is nothing more nor less than a thermos flask."

He removed the flat lid of the flask and a spiral of steam ascended into the shimmering summer air.

"Ye gods," commented Dick, peering into the depths of the canister, "if this is tea, there's enough here to feed a regiment!"

"Not quite a regiment, laddy," replied Smithy, "but you're not all that far off. We used this type of flask in the army to supply a day's tea ration for about eight men."

"Blimey," commented Dick. "When you left the army you must have taken half the stores with you! It would be worth their while starting up another war just so they could call you back again with all your gear. It's the only way they could get their books straight!"

"Nonsense," replied Smithy. "I bought it surplus."

The Serviceman turned once more to his bag and produced a cracked china cup and a once-white enamelled mug. Dick regarded these objects with horrified recognition.

"Those," he gasped incredulously, "are out of the Workshop!"

"Of course they are," said Smithy shortly. "There's no point in leaving them there doing nothing if we can employ them usefully down here. I could just about do with a cup of tea right now, so I'll leave you to get on with the makings."

Grumblingly, Dick took a bottle of milk which Smithy also unearthed from the bag and proceeded to fill the disreputable utensils.

"Dash it all," he complained, "we might as well have brought down a few sets and a couple of testmeters whilst we were at it. I did at least think we'd be able to forget the Workshop for one afternoon."

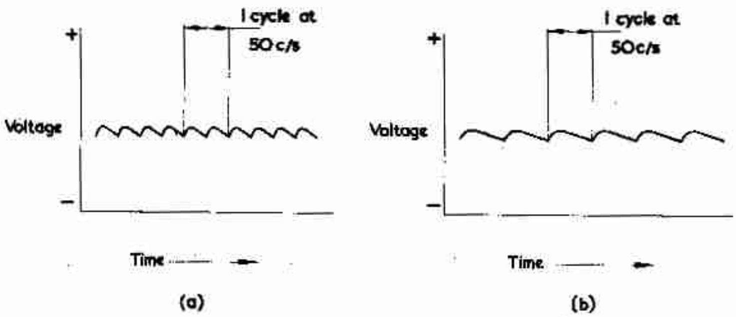

Fig. 1 (a). The ripple voltage from a full-wave or bridge rectifier has a basic frequency of 100 c/s

(b). With a half-wave rectifier, the ripple voltage has a basic frequency of 50 c/s. Due, however, to its non-sinusoidal form, the ripple contains a high percentage of harmonics of the basic frequency

"Stop chuntering," snorted Smithy, taking a deep draught from the mug which Dick had handed him. "In any case, it's *you* who's brought the Workshop with us. All your questions about hum and that!"

"At least," grumbled Dick, "I don't go around showing other people up like you do. I'm certain that everyone's watching us."

There were, indeed, plenty more people around them now who could, if they had a mind to, well enjoy the dubious pleasure of watching Smithy take his afternoon refreshment. The beach had continued to fill up and Dick and Smithy were now surrounded by other searchers after the sun. The ambient noise had risen to quite a high level and several more transistor radios were reproducing the pop record session from the Light Programme. One individualist had, however, tuned in to a play on the Home Service, turning the volume well up to ensure that no word of the action was lost.

"I must say," remarked Smithy, smacking his lips loudly and ignoring Dick's last remarks, "that all this makes a very pleasant change from work."

"Perhaps you're right," commented Dick moodily.

A thought recurred to him.

"You haven't yet," he remarked, "told me what you meant by 100 volt line working."

"Dear oh dear," sighed Smithy, "you never let go, do you?"

"You shouldn't have aroused my curiosity," replied Dick accusingly. "If you'd said nothing about 100 volt line working, I'd never have got curious about it. What does it mean?"

Wearily, Smithy gave way to the inevitable.

"Let's get back," he said resignedly, "to hum. I was saying that I first bumped into this business of the audibility of hum when I was checking high quality public address amplifiers. These had an output of 50 watts or so, and when they were tested for hum their outputs were connected to a resistive load matching into the output transformer and capable of dissipating the full output power. A small bench speaker with a matching transformer was then coupled up in parallel with this load to give an audible indication of what the amplifier was pushing out. Most of the amplifier hum level was pure 50 c/s due to stray heater wiring couplings, and it was measured by connecting a testmeter switched to an a.c. volts range across the output. You could get quite a high reading on this meter without hearing any audible hum from the bench speaker at all."

"What," persisted Dick, "about the 100 volt line business?"

"I'm just getting on to that," replied Smithy patiently. "As a matter of fact, it has nothing to do with hum, but I wanted to finally clear the hum question up first before getting on to it. Line voltage working is, in effect, a simple method of dealing with the matching of loudspeakers to public address amplifiers which are installed in fixed locations. Let's suppose you have a p.a. amplifier which offers an output of 50 watts at an impedance of 200Ω. This is a fairly typical impedance figure with fixed installations, such as in factories or office blocks where there may be long wiring runs to some of the speakers. Let's next say that we want to run 50 loudspeakers from this amplifier. How would you set about seeing that these matched up to the amplifier output?"

"Can each loudspeaker be fitted with its own transformer?"

"Oh yes," said Smithy. "Each loudspeaker and transformer combination is connected in parallel across the output lines from the amplifier." (Fig. 2.)

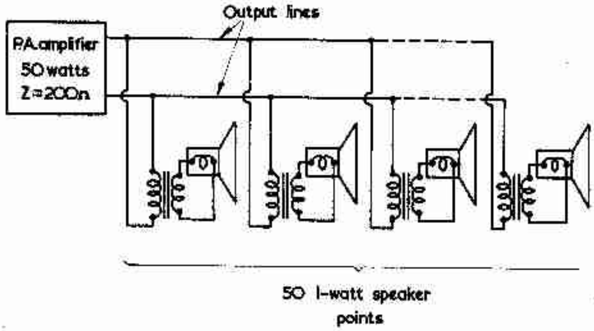

Fig. 2. Coupling 50 loudspeakers to a p.a. amplifier installed in a fixed location. Each speaker point presents an impedance of 10,000Ω to the amplifier lines

"I see," said Dick thoughtfully. "Now, if we have 50 loudspeaker and transformer combinations in parallel, it means that the impedances they present to the amplifier output are in parallel also."

"That's right," agreed Smithy. "For convenience, you can assume that the fact that each speaker has its own matching transformer is understood. Just think in terms of the impedance offered at each speaker point."

"Fair enough," said Dick. "We need 50 impedances in parallel to give us 200Ω. Why, that's easy! Each speaker unit impedance would be 200Ω multiplied by 50, or 10,000Ω. Fifty impedances of 10,000Ω in parallel give 200Ω, which is just what is needed for matching to the amplifier."

"Exactly," confirmed Smithy. "And if the amplifier was pushing out its full 50 watts, how much power would be consumed by each speaker?"

"That's easy, too," replied Dick. "Each speaker would be handling one-fiftieth of the power. Which is 1 watt each."

Different Power Levels

"Fine," said Smithy. "The next step is to consider what happens if we want some speakers to handle more power than the others. Let's say, for instance, that we only want 10 loudspeakers to reproduce sound at 1 watt. This uses up 10 of the 50 watts output provided by the amplifier. Of the remaining 40 watts, let's assume that we want 4 speakers to work at 5 watts and 2 speakers to work at 10 watts. (Fig. 3.) How do you sort out the impedances at the speaker points then?"

"You're becoming," commented Dick, "a bit more complicated now. Why do you want all these different powers anyway?"

"It depends upon where the speakers are positioned," explained Smithy. "The speakers which consume 1 watt could, for instance, be installed in small offices where there's only a low noise level. The speakers working at 5 watts could be fitted in, say, a small hall; and the ones working at 10 watts in a larger hall or a more noisy location."

"I see the point," admitted Dick. "But it looks as though it's going to be a bit of a problem to work out."

"It *is* rather a fiddling calculation," admitted Smithy. "When you work from the point of view of impedances in parallel. A much easier method consists of using the idea of line voltage working. If we connect our amplifier up to a 200Ω load resistor (Fig. 4), what voltage do we get across the resistor when the amplifier feeds its full 50 watts into it?"

"This bit's simple!" said Dick. "$P=\frac{E^2}{R}$ where P is power in watts, E is e.m.f. in volts and R is resistance in ohms. So in this case $50=\frac{E^2}{200}$. Shift the 200 over to the left-hand side and you get $50 \times 200=E^2$. Just a minute! 50 x 200 is 10,000, so $10{,}000=E^2$. Now, what's the square root of 10,000? Why, it's 100 of course! So 100=E."

Smithy looked at Dick in grudging admiration.

"Your mental processes never cease to baffle me," he remarked. "Only you could have gone through that entire rigmarole with E on the wrong side of the equation!"

"I'm right, though, aren't I?" asked Dick belligerently.

"Of course you're right," replied Smithy soothingly. "We've now learnt that the amplifier offers 100 volts output when it's connected to its correct load. So we say that we have a 100 volt line. We could, by the way, get different line voltages by varying the output power or the output impedance. Our next job consists of finding the impedance which is required at each speaker point to provide the desired power output. We'll start off with the 1 watt speakers."

Smithy carefully brushed a few grains of sand from the rim of the enamelled tin mug, and drank deeply of its contents.

"Ah, that's better!" he remarked appreciatively. "Now, let's get on with these 1 watt speakers. Each speaker unit has to draw 1 watt of power from the 100 volt line and so we employ the same formula as before, except that we now use Z for impedance instead of R for resistance. It is assumed, incidentally, that the impedance is resistive. Now, $P=\frac{E^2}{Z}$ or $Z=\frac{E^2}{P}$. This gives us, for 1 watt, $\frac{100^2}{1}$ or 10,000Ω. Thus, each 1 watt speaker point has to offer an impedance of 10,000Ω to the line if it is to consume 1 watt from it."

"Well, that's nice and easy, too," remarked Dick. "Let's have a bash at the 5 watt speakers next. $P=\frac{E^2}{Z}$, so $5=\frac{100^2}{Z}$. Therefore $Z=\frac{100^2}{5}$ or 2,000Ω. With the 10 watt speakers you have $10=\frac{100^2}{Z}$, with the result that $Z=\frac{100^2}{10}$. So you have an impedance of 1,000Ω."

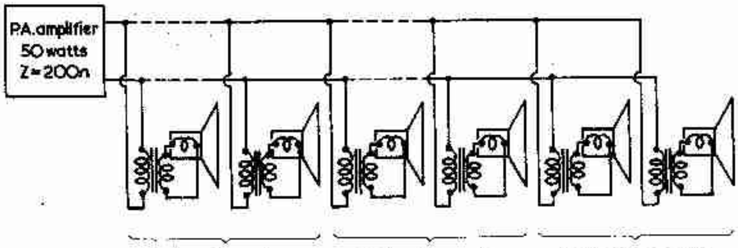

Fig. 3. An alternative p.a. speaker installation

"That's the idea," confirmed Smithy. "And I'm glad to see that you eventually got Z over to the left hand side in both cases! You end up with 10 speaker points at 10,000Ω, 4 speaker points at 2,000Ω and 2 speaker points at 1,000Ω." (Fig. 5.)

"I suppose," said Dick a little doubtfully, "that you *will* get the correct impedance of 200Ω if you work out the total impedance given by all these speaker points."

"Definitely you will," confirmed Smithy. "To start off with, you've got 10 speaker points at 10,000Ω each, so their total parallel impedance is 1,000Ω."

Smithy traced out this figure in the sand.

"You next," he continued, "have 4 speaker points at 2,000Ω, so these give a total parallel impedance of 500Ω. Finally, you have 2 speaker points at 1,000Ω, which also give you 500Ω. The two sets of 500Ω impedances combine together to give you 250Ω, and so the total impedance is 1,000Ω in parallel with 250Ω."

"That shouldn't be too hard to work out," said Dick, rolling over and tracing out a calculation in the sand alongside Smithy's figures. "1,000Ω and 250Ω in parallel gives you $\frac{1{,}000 \times 250}{1{,}000+250}$, which is $\frac{250{,}000}{1{,}250}$. Knock off the end noughts and you get $\frac{25{,}000}{125}$. Which is, of course, 200Ω. Piece of cake, isn't it?"

"Dead simple," replied Smithy. "And it proves that, by using the line voltage working idea, we not only present the correct impedance to the amplifier, but we also tap off the required wattage ratings at each loudspeaker location as well. As I mentioned just now, we treat the impedances at the speaker points as though they were resistive, and this is quite acceptable for the application."

"What about the actual loudspeaker impedances themselves?" asked Dick. "Could these be, say, 3Ω or 15Ω, or something like that?"

"Oh yes," replied Smithy. "You have a matching transformer at each speaker, as I said earlier on. The turns ratio in this transformer is then equal to the square root of the impedance ratio. If you have a 3Ω speaker and want it to present 1,000Ω to the amplifier line, the turns ratio in the transformer is the square root of $\frac{1{,}000}{3}$ or 333. Which works out at something like 17:1 or 18:1 or so."

It was Dick's turn to gaze with admiration at his partner.

"Did you actually," he remarked, "work out that square root in your head?"

"Not really," admitted Smithy. "It was just a rough guess using squares which I've learned to remember off by heart. The square of 15 is 225 and the square of 20 is 400. Since 333 comes roughly in the middle of 225 and 400, its square root should, similarly, come roughly between 15 and 20."

Other Line Voltages

"I must say," said Dick enthu-

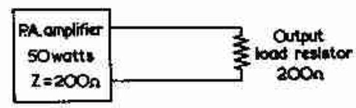

Fig. 4. Coupling the amplifier of Figs. 2 and 3 to a 200Ω load resistor

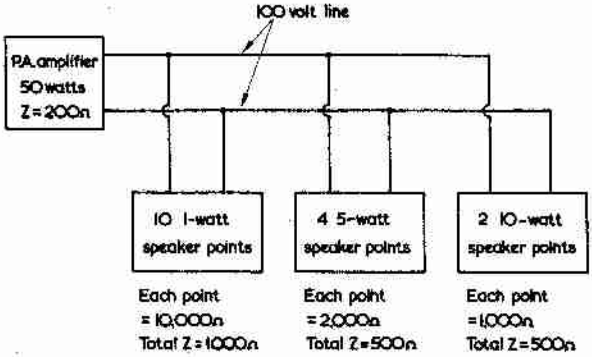

Fig. 5. Demonstrating the impedances offered by the speaker points illustrated in Fig. 3

siastically, "that we haven't half been delving into the old basic theory this afternoon, even if we are on the beach. This Pythagoras act is really something!"

"Pythagoras act?"

"Doing these sums in the sand. That's how Pythagoras worked out all that jazz about the square on the hypotenuse."

"Wasn't he the chap who invented resistance wire?"

"Hey?"

"That's right," continued Smithy. "He jumped up in his bath and called out 'Eureka'!"

"Blimey," said Dick. "Just how corny can you get? Anyway, that was Archimedes."

"Archimedes invented the Archimedean screw," stated Smithy. "It was frequently used in Greece in the old days."

"I always thought", said Dick, "that he was the immersed body geyser. You know, a body immersed in a fluid loses weight according to the weight of the fluid it displaces. Talking of that, incidentally, when are you going to immerse that body of *yours* in some fluid—namely the sea—and similarly lose a bit of weight?"

Smithy looked down at his middle regions.

"I can see no reason why I should lose weight," he remarked. "A certain portliness is, I feel, becoming to a person of my age and stature."

"You certainly keep it well covered anyway," commented Dick, critically surveying the Serviceman's abdomen. "Where on earth did you get those enormous drawers?"

"My swimming costume," replied Smithy with dignity, "offers complete comfort combined with a decent and discreet covering of the limbs. A large costume has the further advantage, in my case, of hiding my appendicitis scar."

"Do you mean to say," asked Dick incredulously, "that they found your appendix in *that* lot. They must have charged a search fee!"

"Whuff," said Smithy.

This extraordinary utterance was not intended as a reply to Dick but was occasioned by the forceful descent of a heavy beach ball on the exact centre of Smithy's stomach. The sudden appearance of the ball awoke Dick to a realisation of the world about him. By now the bay was fully crowded, and he was surprised to find how closely hemmed in they were on all sides. The radios about them continued with their various renderings of the Light Programme and the Home Service. Even as Dick watched, a young man sat down to produce a further transistor radio, which he tuned in to a cricket commentary on the Third Network. Things were settling down to the usual British version of an afternoon at the seaside.

"Oh," said a youthful female voice. "I'm *so* sorry."

The owner of the voice stepped daintily over the recumbent bodies about them and extended two sun-honeyed arms to pick up the beach ball at Smithy's side. Dick looked up to see a slender feminine figure hovering gracefully above him clad in the dinkiest of bikinis. An exquisite smile appeared on the face of this vision, and he became lost in the depths of two clear blue eyes.

"That's all right," he stammered eventually.

"Oh, I'm so glad."

The voice reminded Dick of the murmuring of bees in a sun-drenched garden.

"In any case," continued Dick, indicating the rhythmically puffing Serviceman, "he doesn't mind."

"I'm so glad," repeated the girl.

Slowly she turned away to make her way delicately through the crowds and their paraphernalia. She turned round to give a long glance at Dick, then finally disappeared.

Smithy returned to normality.

"Phew," he rumbled. "That gave me quite a turn."

He turned to his outsize flask, refilled his outrageous mug, quaffed deeply of the restoring liquid it contained, and returned to a supine position on his back.

"Now where were we?" he remarked, collecting his thoughts. "Oh, yes, we were talking about 100 volt line working. I think I should add that there are other standard line voltages as well, these being at 60, 80 and 120 volts. However, the 100 volt line is that which appears to be most common. If the public address system has to reproduce music and there are long wiring runs to the speaker units, self-capacitance in the cable can sometimes be a nuisance because it causes attenuation of the higher audio frequencies. This effect can be reduced by going down to lower line voltage working.

"Another point," he continued, "is that the wattage figures I talked about just now were meant mainly to illustrate the method of working out speaker impedances. In practice, an office usually requires about 2 watts, whilst a fairly noisy factory shop may require anything from 20 to 100 watts or more overall, according to its size and general noise level. Yet another factor . . ."

The Final Scene

Suddenly aware of an absence of comment, Smithy broke off and turned over to look at his companion.

But Dick was gone.

Smithy sat up and surveyed the area around him. There was no sign of Dick anywhere at all. He had become completely swallowed in the teeming mass which now thronged the beach.

"Oh well," commented Smithy philosophically to himself. He poured himself yet another draught of tea, then lay back and allowed the various sounds of the beach to flow over him. Idly his ears responded to the triad combination of Light Programme, Home Service and Third Network which pervaded the air.

A thought struck him, and he started to rummage in his bag, eventually producing a large and powerful-looking transistor radio. He switched this on and selected the medium wave band.

Carefully, he searched for Radio Caroline . . .