

Radio Underground: a collaboration of diverse skills.

The challenge of introducing wireless communications to the mines of South Africa.

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In a world where instant communications, using the ubiquitous cell phone, are simply taken for granted these days - and almost regardless of where one happens to be - it surprises some people when they discover that it's not like that everywhere.

Miners, for example, rather like submariners, know that radio goes nowhere when one's world is hemmed in by solid rock; or, in that other very confined environment, when it's surrounded by salt water. But it can be done (in a rather more limited way, one must concede) by using technology somewhat different to that in the latest *Droid Maxx* from Silicon valley or any *iPrefixed* phone from an orchard nearby.

Gold mining in South Africa essentially began in 1886 when George Harrison, who had no pretensions as a guitarist and sometime singer, turned up a chunk of what came to be called "reef" and which soon spawned an industry that changed the country's history. But that was a stray find and the search for the reef, in earnest, soon went deep underground and mining, at ever-increasing depths, became a serious business. Fifty years later, dozens of deep vertical shafts, identified by their steel headgear, dotted the Witwatersrand from east to west across Johannesburg. Those shafts were connected to miles of "travelling ways" underground that finally ended at the "stopes" where the reef was removed. There, miners worked - mostly doubled up - as they drilled, blasted and, finally, despatched to the surface that precious gold-bearing ore. It was dangerous and accidents occurred. And when they did, and especially when fire broke out or when the rock literally "burst",

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thousands of feet below ground, the death toll was often high and rescue was both slow, perilous and always *incomunicado*.

In 1938, the medical adviser to the Rand Mines Company, Dr A J Orenstein, asked the Chamber of Mines to investigate whether radio communication was possible underground. Evidently, a British company claimed that it had the equipment but Orenstein sought convincing evidence. Before it came, one way or the other, war had broken out in Europe, and then across the globe, and all attention was focused elsewhere.

South Africa's mines worked while the world was consumed by war and the gold recovered from deep below the ground sustained its economy. Accidents and acts of God occurred, just as they'd done before, but then, with peace declared in 1945, the Chamber approached the CSIR with a request that someone might pronounce on the possibilities of using wireless communication in the mines. The CSIR was the brainchild of Field Marshal Smuts. It was a post-war creation staffed by men with scientific training who'd only shed their uniforms a matter of months before. Acting on the Chamber's request, an investigation was mounted at the CSIR and a report on the feasibility of using radio underground was written by T.L. Wadley, then unknown but soon to become a local legend. Wadley showed mathematically, but backed up by experiments, that it was possible to send radio signals some hundreds of metres through rock as long as certain conditions were met. The first and most important was that only low frequencies would propagate over a useful distance. However the technology of the time imposed many limitations; of which the most important was the size and weight of the equipment. It will be remembered that in those days wireless sets used thermionic valves and they tended to be big and bulky. They also needed large, heavy batteries when portable.

No doubt for that reason (but possibly for others not related to the technology at all) the mining industry failed to act on Wadley's report and it ended up in the library.

A decade later, when the Chamber's own research organization came into being, the use of radio underground

was one of its first, challenging, research projects. Wadley's report was dusted off and (intriguingly) the task of at least testing its recommendations was given to the recently-formed Dust and Ventilation Laboratory, and specifically to its Electronics Division. Relying heavily on Wadley's work, Dirk Vermeulen, an engineer within the Electronics Division, set about developing suitable radio equipment for use within mines by the so-called Proto teams whose task it was to tackle fires underground. "Proto" referred to the particular type of breathing apparatus worn by those team members.

Ultimately, after some considerable R&D of his own, Vermeulen and his boss, Paul Blignaut, published a very detailed paper in the Transactions of the SAIEE in April 1961. It discussed the underlying theory, based on Wadley's report, and also described the radio equipment they had developed in their laboratory. It consisted of two sets of equipment: a portable set to be carried (or more specifically "worn") by a Proto team member and a semi-portable base-station plus its unusual, wagon-wheel sized, loop antenna. The equipment operated at 335 kHz, a frequency that emerged, after careful study of the Wadley report, as being just about optimum for the task.

Except for three transistors in the audio output stage of the base-station receiver, the rest of the equipment used thermionic valves. The base-station produced 10W of power, amplitude modulated (AM). The portable set generated only keyed continuous waves (CW) for the reason that its operator, wearing breathing apparatus, could not talk because, clenched between his teeth, was his breathing tube and pinched across his nostrils was a nose clip. The portable transmitter, which produced about a watt of power, was incorporated within a fairly substantial ridged supporting bracket that was effectively worn across the operator's shoulder and torso. Its multi-turn loop antenna was wound within that supporting structure.

Not too surprisingly considering his now much encumbered situation, the portable radio operator was not also expected to learn the Morse code. Instead, a much simpler code of dots and dashes, based on appropriately phrased questions put to him by the base-station operator, was developed. It was believed that this would suffice as a means of communicating, even in moments of duress and under

considerable stress. Clearly, only operational experience would show whether that was true.

The Blignaut and Vermeulen SAIEE paper showed, following extensive testing in a number of operating mines across the Witwatersrand, that this particular apparatus met its basic objectives of providing useful communication range directly through rock. A useful adjunct to this work was the discovery that increased range occurred whenever metallic conductors such as power and telephone cables, and even pipes and rails, were nearby.

But the sets were heavy and though the Proto teams participated willingly in a series of subsequent trials, their verdict was that the bulk and weight of the equipment would prove more of a hindrance than an aid when fighting a really aggressive fire underground that required every man to drive himself almost to the limit of human endurance.

And that's where the underground radio project apparently stalled for many years until electronic technology "caught up". The break-through was the progress being made in the semiconductor industry as transistors began to replace valves in much of the electronic equipment of the day. Soon, transistors were available that could function at high frequencies and at increasingly higher power levels. In addition, single-sideband (SSB) modulation had been shown to be far superior to AM. But by then Vermeulen was about to leave the Chamber's laboratories for other challenges and so the task of designing the next generation of underground radio equipment was given to industry. The company chosen was IMC (Instrument Manufacturing Company) in Cape Town who were involved, at the time, in turning Trevor Wadley's revolutionary microwave-based distance measuring equipment, known as the Tellurometer, into an industrial product. The IMC engineer entrusted with the underground radio project was F.G.Clifford.

Clifford designed, and IMC manufactured, five prototype SSB manpacks that produced 10W of power at a single frequency of 335 kHz. They were completely solid-state and weighed no more than a few kilograms each. When on the move each used a small, multi-turn loop antenna cleverly conceived by Paul Blignaut at the Chamber labs in an elliptical shape. The advantage this gave the loop over its more usual circular configuration was that it was easier for the operator to slip across his upper body. For the same enclosed area as

its circular counterpart, the ellipse was less of an encumbrance and was also less likely to become snagged in nearby objects. It was altogether more "ergonomic", a term then coming into vogue before "user-friendly" made its appearance!

For the base-station, when situations required that one be deployed, a much larger loop (usually consisting of just a single turn) was erected around the walls of the tunnel and then brought to resonance and matched to the correct impedance by a suitably-housed network of capacitors.

Though most effective when used underground, and easy to operate (even though the CW limitation still applied to the Proto-man on the move), it would be true to say that the management of the Chamber's Rescue Training Station, where all Proto teams learnt their trade, were hardly swept off their feet by this "box" of electronics which they had to hump around along with all their other vital gear. So, once more, the requirement for better communications between those fighting underground fires and their control, or "fresh air", base had not been satisfied and it was beginning to look as if it was a quest that was just one bridge too far. But to Paul Blignaut it was now apparent that there were surely other applications for radio communications underground within mines - and not just those that were digging out gold. He set out to investigate these and to demonstrate the capabilities of the new SSB manpacks across the South African mining industry. His labour paid dividends for their initial reaction was positive enough to suggest that radio did indeed have a role to play in many areas of underground mining and not just in emergencies.

In addition, and for completeness, he and his colleague Arthur Atkins made a detailed investigation of all forms of communications, both wired and wireless, then being used in mines worldwide and their findings were published in an important internal Chamber research report.

It was at this time that a callow youth (the author of this story) joined the Chamber of Mines Research Organization - as its name had now become. With an electrical engineering degree from Wits, a short burst in the military electronics industry (with Fuchs Electronics), as well as a decade as an avid radio amateur behind him, he jumped at Paul Blignaut's suggestion that he take the lead in the

underground radio project. Gerry Meaker became the technician charged with turning circuit diagrams on paper into reality. Initially, though, there wasn't much of either because they both spent much time underground getting a "feel" for how radio worked in a lossy dielectric medium, as the geology of a mine is described by all electromagnetics theoreticians.

Research is a curiosity-driven activity and so it was natural to want to see how poorly (since this is what the theory said) a VHF signal would propagate along a mine tunnel. Tests were conducted using (borrowed) VHF "walkie-talkies" and, indeed, it was discovered that it was often possible still to shout to one's colleague long after the radio transmission had disappeared into the noise. But frequencies just below the medium wave broadcast band, as generated by the 335kHz SSB manpacks, propagated well beyond line-of-sight and even between different levels of a mine with a couple of hundred of metres of rock between transmitter and receiver. Wadley's graphs therefore carried even more weight than even their illustrious provenance suggested they should.

But what was quite apparent from the reaction of all on the mines who'd witnessed the radio demonstrations was that the sets were too big and bulky. And though they'd not yet seen how small so-called cell phones would become, for they were still some twenty years to creation, the clear objective was something small enough to be held in one hand.

However, the real impetus that such a transceiver was needed came not from those mine visits but from the most important project then underway within the Chamber's research organization itself: automation of the gold-mining process. Conventionally, gold-bearing reef had been blasted out of the host rock by explosives and then transported, in bulk, to the surface for processing. This whole activity suffered from numerous disadvantages not directly relevant to this account so we won't dwell on them here.

In the early-1970s the Chamber's Research Organisation began an investigation into alternative methods of recovering the gold-bearing reef. Instead of blasting by dynamite it seemed feasible to use mechanical means to break or even "cut" the rock. Such concepts needed extensive testing and an experimental stope, equipped with automated machines, came into operation deep underground at

the Doornfontein goldmine, near Carletonville, west of Johannesburg. The intention was to evaluate and assess the performance of various prototype rock-cutting machines. In all there were eight of them located over a distance of some two hundred metres and each had its dedicated machine operator. In addition, a maintenance team, based at an underground store some few hundred meters away, serviced all those machines. It soon became apparent that the lack of communication between the machine operators and the supervisory and maintenance teams seriously impeded the progress of the project. The credit for thinking laterally and realising the need for some means of radio communication must go to John Bradley, the project supervisor whose virtual home was that underground store at Doornfontein.

It so happened that a much smaller transceiver was then under development, by Austin and Meaker, within the Chamber's Electronics Division. It was handheld and operated at the higher frequency of 903 kHz, a figure that was determined by the rather novel circuit topology adopted by its designer, but close enough to 1 MHz which analysis had shown would yield excellent results over distances of a couple of hundred metres, directly through rock, with a power output of 1W PEP. The transceiver was soon to be called the TXR-1.

Bradley's foresight and the coincidental development of this new equipment soon provided a very effective solution to a pressing problem at Doornfontein. A higher-powered base-station, plus a large loop antenna, was set up in the store and every machine operator was issued with a radio transceiver and trained in its use. In addition, all the maintenance personnel responsible for keeping the rock-cutter experiment going were similarly equipped and trained. The radio network functioned very effectively indeed and it was soon acknowledged by those directly involved in overseeing the project that this mechanised stope could not have functioned without it.

However, this sudden need for rather more radios than the Chamber's research laboratory would typically wish to manufacture led in 1975 to their production, in sufficient quantity, by a small electronics company in Johannesburg. Surprisingly, given their light-weight plastic enclosures and protection by little more than a simple canvas pouch,

the TXR-1 stood up remarkably well to the rigours of mining and to their often less than tender handling by the miners.

This use of radio as part of a major research programme was, in fact, the first time that radio communication played any part in the underground mining process in South Africa.

The base-station referred to above was an important development aimed at increasing the communications range. It made use of the same transceiver module as the TXR-1 but augmented it by the addition of a 10W transmitter power amplifier. Likewise, the receiver's output was similarly boosted and it usually drove a large horn loudspeaker - a vital component in a very noisy mining environment.

Tests had shown that the use of these base-stations, linked by simple two-wire lines, and even to the mines' existing telephone networks, could provide very effective communications over considerable distances. In addition, the adventitious coupling of radio signals into all metallic conductors in the vicinity of their antennas was now well known as a means of extending communication range. Truly wide-area coverage (at least within the mining context) was now a feasible proposition.

A memorable experiment took place at the West Driefontain goldmine, near Stilfontein, in 1976 when voice contact was made by Graham Lambert, one of the Chamber's electronics personnel, who was some 2km below ground and within the confined area of a stope, with his boss, Arthur Atkins, who was sitting at his desk in his office in Johannesburg. Lambert was using the 903 kHz transceiver in conjunction with a distant base-station that was acting as a radio broadcast transceiver able to serve an area of some thousands of cubic metres of rock. The base-station, in turn, was connected via two-wire line and the mine telephone network to the surface and from there to the GPO telephone network by the simple expedient of holding two handsets together.

This demonstration of the capability of a remotely-operated radio system underground suggested a host of other applications. The most significant of those was within the highly automated coal mines of South Africa.

Austin's team of technicians had by now been augmented, not just by Lambert, but also by another product of the General Post Office's excellent training facilities, Jimmy Odgers. Soon they were joined, in 1975, by Martin Higginson, an electronics circuit designer of great flair and originality who'd been a colleague of Austin's at Fuchs Electronics. Together these men pioneered the design and development of the next generation of radio equipment intended for use in South Africa's massive mining industry.

In parallel with this laboratory effort, Austin had been conducting a series of radio propagation experiments in a worked-out section of the Durban Deep gold mine near Roodepoort and not far from the Chamber's research laboratories in Richmond, Johannesburg. The purpose of these tests was to confirm, in the first instance, whether Trevor Wadley's predictions of the optimum frequencies to use underground were borne out in practice. In addition, since the test area contained no metal conductors of any sort, it was the ideal site to investigate the "through-rock" propagation mechanism and to identify any special radio propagation features that might be influenced by the geology of the surrounding rock.

The frequency range to be studied extended from the 335 kHz of the original underground radio designed by IMC in Cape Town to close to 10 MHz in the high-frequency (H.F.) band, typical of many shortwave applications. Research carried out in the USA had suggested that such higher frequencies might well prove useful under certain geological conditions. It was Austin's intention to investigate this. But the availability of suitable equipment to do so was a problem.

It could have been designed and constructed "in house" but the need to divert the meagre resources from other more pressing requirements made some other approach more attractive. Fortunately, South Africa possessed a vibrant military electronics industry and Racal (South Africa), in Pretoria were the undoubted leaders in high-frequency radio technology. David Larsen, Racal's MD, was an active radio amateur and he and Austin were well acquainted. A phone call to Pretoria and a brief explanation of the need saw Larsen offering to lend the Chamber of Mines two military manpacks that covered the frequency spectrum required. The manpack in question was the remarkable TR28, a single-

sideband (SSB) transceiver capable of 25W PEP output and clearly rugged enough to be used underground.

The propagation tests conducted at Durban Deep showed that radio signals, propagating through rock, are attenuated almost exponentially as the frequency is increased. This was in line with electromagnetic theory and essentially confirmed Wadley's findings. The tests also showed that of the two antenna types used - the small loop and the short whip - the former was much the better, both electromagnetically and practically. This was a useful result and it confirmed what became known as the "body-loop antenna" as the standard radiator for all further portable communications underground.

Based on the success of the 903 kHz SSB handheld transceiver in the rock-cutter stope, and the likelihood that similar applications must surely exist for radio communications underground, especially in the automated coal mines, Austin and Higginson set about designing the next generation of radio equipment. It was clear that a multi-frequency capability would be needed if radio communications between miners, equipment operators, maintenance personnel and others was to be used in a fairly small and congested area. Each operation, or net as it's known in radio parlance, would probably need its own "channel" to avoid mutual interference. The frequency range to be covered by the equipment had been clearly identified by the success achieved with the 335 kHz manpacks and the more recent achievements of the TXR-1 operating just below 1MHz. And so it was decided that this new apparatus would work from 100 kHz to about 1MHz. The same power output as the TXR-1, namely 1W PEP, with suitable "speech processing" to optimise the dynamic characteristics of speech, were also agreed.

There was another important factor that influenced this decision on maximum power output and that was the need for electrical and electronic underground to be "Intrinsically Safe" (I.S.), especially if used in coal mines where the risk of methane gas explosions is high. The I.S. requirement could easily be satisfied at a power level of 1W, and since operational experience had shown it to be entirely adequate for most applications, this power limit was confirmed.

Additionally, the likely close proximity of radio nets to one another meant that it was also imperative that the radio receiver in the equipment should be able to operate normally even in the presence of very severe interference. This implied that the receiver should have a wide dynamic range. Again techniques for ensuring this were well-known.

It was now clear that a sophisticated piece of electronic hardware was needed. Its similarity, in many respects to current military radio equipment was clearly apparent. But that posed no problems because both its designers had been exposed to such rigours in their previous employment.

In just a couple of months, Martin Higginson produced two prototypes of the equipment and in January 1977 they underwent laboratory testing. The results looked extremely promising and underground trials soon followed. The successful outcome indicated that this new equipment was indeed viable and consideration now shifted to having it produced commercially and made available to the mining industry, both locally and internationally where, clearly, it should also find applications.

Negotiations were then entered into with Racal (South Africa), with a view to their turning the Chamber's prototype into an industrial product. Arthur Atkins and Brian Austin of the Chamber's Research Organization and David Larsen, MD, of Racal (South Africa) met several times early in 1977 to work out the details. Visits were then paid to the Chamber's Electronics Division laboratories by senior Racal engineers Adrian Cocciuti and "Apie" de Jager to view the prototype transceiver and, no doubt to assess the competence of its designers! Joint design meetings soon followed at the Waltloo factory of Racal. These were always chaired by Willy van Lochem, Racal's chief engineer. Also present were Eric McMillan, who was to handle the re-engineering of the electronics aspects to meet Racal's particular requirements, and Dave Atkins, Racal's industrial designer, who took on the most important task of producing a suitable plastic enclosure for the radio that would satisfy a number of stringent requirements. Brian Austin was the Chamber representative at every meeting. Occasionally he was accompanied by Arthur Atkins and frequently, too, by Martin Higginson.

Excellent progress was made. In April 1978 a press release appeared from Racal announcing the commercial launch of the

SC100 "substrata communicator" with its bandolier-style loop antenna that doubled as a mounting strap. It was capable of working on selected frequencies between 100 kHz and 1160 kHz at a power level of 1W PEP. Another important aspect, especially from the point of view of the miner who had to carry it, was that it weighed no more than a kilogram.

The marketing of this mining communications equipment presented a new challenge to Racal, soon to become part of the Grinaker group. Until now the great majority of their customers had always been military men and Racal's well-oiled marketing organisation was specifically geared-up for dealing with them. Now, mine managers and miners would form the customer base. In some ways, given the very tough environments in which both operated, there were more similarities than differences between these two groups of strong-minded individuals so the transition was not too traumatic. To handle the sales, and especially the introduction of a completely new technology to the mining industry, Larsen made a brilliant choice. He appointed the recently-retired Brigadier Norman Orsmond, formerly Director of Signals of the Rhodesian Army, to the post of running SECOM, a new company set up within the Grinaker Electronics Group, for the purpose, specifically, to market the mining communications equipment.

Norman Orsmond was soon introduced to mines and their inhabitants by Brian Austin who arranged a number of underground visits so that the former soldier could see the new radio sets in action and also meet some of those who might end up using them.

The visits also presented opportunities for the Racal/Grinaker personnel to experience the world underground while putting the radio sets through their paces. On one memorable occasion, when Austin had requested their hosts to select a test area that included a series of very narrow tunnels only accessible on all fours, a rather rotund Eric McMillan, with SC100 wrapped around his torso, presented something of a challenge to those attempting to ease him through a very confined passage. But he emerged with a smile on his face because, throughout the process, he told us "his" radio had worked very well while emitting comforting sounds of encouragement from its loudspeaker.

It was now clear that the original application for which radio was first considered for use in mines - rescue and fire-fighting - was an obvious candidate for the SC100. The set itself was considerably smaller and lighter than anything else ever tried by the Rescue Training Station (RTS). In addition, it offered considerably improved performance by virtue of its more modern design concepts.

As soon as they saw the equipment, and had it demonstrated to them, the management of RTS expressed interest and so a series of underground trials was set up. The SC100 and a hastily-configured base-station using another one performed very well. Of especial importance was the ease with which the Proto team personnel could both carry and operate the equipment. By now their own equipment had also seen some significant advances with the use of a full face mask that allowed the inclusion of a microphone. Gone was the need for clumsy codes operated by pushing a button with gloved hands. Speech communication would be the norm henceforth.

Secom's first bulk order came from RTS when a number of SC100s and the new SC200 base-stations were delivered, in late 1978, to the RTS Rosettenville headquarters. As always with radio communications equipment, proper training in its correct use is vitally important. And no one does that training better than the signals corps of any army, so the former Brigadier Orsmond, now under a hard hat of both different colour and shape to its camouflaged predecessor, introduced that training and the RTS Proto teams soon became competent radio operators.

Plaudits weren't long in coming. Following a fire at the West Driefontein mine that was tackled by a Proto team equipped for the first time with the new radio system, their captain, one Eddie Ryan, was succinct and to the point: "[the SC100] is the answer to a Protoman's prayer", he said. Recognition also came from another quarter. The Design Institute of the South African Bureau of Standards selected the SC100 and its designers at Grinaker Electronics for the Premier Award in the Engineering Products section in 1978. The local press also made much of this "mining breakthrough", as more than one newspaper called it.

International exposure to this South African-developed technology came at a conference held in Boulder, Colorado in March 1978. Brian Austin presented a paper on radio

communications underground in South African mines and used the opportunity to meet fellow researchers at a number of US and British institutions engaged in similar work. In many respects the South African equipment was unique as it was intended to radiate radio signals directly through the rock. By contrast, in almost all other applications, radio was used in conjunction with specially installed cables that guided the signals along tunnels and into working areas. Though of interest, it was generally agreed that these so-called "leaky feeders" would not have survived long in the challenging conditions of a South African gold mine. But the South African system did use existing cables to achieve much the same purpose and that method of extending communication range was the basis for a number of very successful installations in South African coal mines where automation was the order of the day.

A detailed study of the electromagnetic processes involved in this guided-wave communications was conducted by the Chamber's research laboratory at two coal mines: Greenside Colliery, near Witbank, and Delmas Colliery. Tom Nelson, a recent graduate, who joined the Chamber in 1977, was subsequently awarded an MSc(Eng) degree for this excellent piece of work.

One issue that was not considered to be a major problem when the original underground radio specifications were drafted was that of electrical noise. In mining emergencies it is generally standard practice to switch off all electrical power within an affected area. This reduces both the risk of fire and also makes rescue operations safer. As a result, such sources of electrical noise disappear. However, in a normal operating mine - especially where electrical machinery is involved - then electrical noise will exist. It can have a seriously degrading effect on radio communications because it is both conducted along, and radiated from, all electrical conductors underground. Tests conducted in those coal mines confirmed that electrical noise could well be the factor that limited communications effectiveness more than any other. Various measures were available to mitigate its effects and they were implemented but the issue of noise still remained an, as yet, unresolved problem.

The last investigation undertaken by the author before he left the Chamber of Mines and entered academia was an examination of a different modulation method in the radio

equipment to see whether any beneficial effects would result. This was carried out in conjunction with his colleague, Tom Nelson. As is well-known, frequency modulation (FM) is inherently better-suited than amplitude modulation (AM) to combating electrical noise. Single-sideband (SSB), the mode used in all the existing underground radio equipment, is also a form of AM and so suffers from its same disadvantages in an electrically noisy environment. An experiment was mounted to compare the performance of equivalent SSB and FM systems, operating at 340 kHz, both in the laboratory and underground. It was soon shown, and quite unequivocally, that FM had decided advantages when all the relevant factors were considered. There the matter rested as a research finding; its implementation was another matter entirely.

The history of radio communications underground in South Africa's mining industry is certainly chequered. Looked at chronologically, one is immediately struck by the fact that it stuttered between sporadic bursts of activity - often pretty intense - and intervals in between when no one showed much interest. Since the period between its peaks and troughs was around five or six years, at least in its early days, it didn't take much appreciation of history (or physics) to see some similarity with the 11 year sunspot cycle!

Technology played a critical part too. The sheer bulkiness of apparatus designed using thermionic valves, and the motorcar batteries needed to power them, ruled out its use in the early days. And then, when transistors first appeared, they couldn't operate at frequencies much above the audio range so, again, valves held sway and size was still a severely limiting factor. Eventually, the "all solid-state" equipment appeared and a significant reduction in both size and weight became feasible. In addition, by now the technology of mining was changing, specifically in coal mines but also, at least experimentally, in one specially-equipped gold mine where automation was being tested and those machines required maintenance. And that, naturally (or so one would assume) meant that better communications were surely vital. Thus, radio went into service on a daily basis for the very first time underground in South Africa.

The way was now open for a commercial company to enter the field and so what until now had been a purely "in-house"

exercise within the Chamber of Mines gave way to a collaborative one with a major manufacturer of military electronics equipment. Within a relatively short space of time more than one hundred of the new "substrata communicators", as the small portable sets became known, had gone into service across the gold and coal-mining industries and many more applications for the sets were being actively pursued. But, once again, after an initial flurry of interest and activity it all stalled. Purported reasons were seemingly all down to economics. The mining industry, though initially intrigued by the possibilities that radio seemingly presented to them, was not prepared to pay around R600 per set. Though a miniscule sum in the context of mining, it was seen by some as expenditure on mere ephemera in the overall context of an industry that was based on massive engineering infrastructure and much human effort and sweat. Talking to each other by radio was, in the view of many mine managers, not what mining was all about.

And so, despite the considerable efforts of some within the Chamber of Mines Research Organisation (or COMRO, as it'd become), as well as by a small team from Racal (South Africa) or Grintek as it subsequently became, the project once again petered out in the early 1990s and the persons concerned on the electronics side of this (ad)venture moved on to do other things.

One must ask whether there were any other reasons for this interesting cycle of events, spread over many decades, which saw the rise and fall of radio technology as applied to mining, at least in South Africa? There were, and perhaps the most important of those was the lack of any concerted effort by the Chamber's Research Organization to conduct an analysis of mining from the point of view of how it might've been improved by the use of better communications between (some of) its personnel. Of course, there were applications - such as during emergencies - that almost suggested themselves. And there were others, though initially very few, which came about in the process of attempting to automate gold mining. But, and this is important, it happened in that particular case because of the far-sightedness of one man who was directly involved. In general, a form of technological myopia was much more common. In coal mining, even though automation was almost standard practice, radio's sporadic and rather limited use never prospered - even there. And there were other

applications too, especially in raise-boring, where radio had been shown to be highly effective in improving operational effectiveness, but the interest was seemingly no more than a passing phase; again due, probably, to the drive or speculative interest of one mine manager or other official.

What should have happened was a concerted and properly structured investigation using the formal methods of Operational Research (O.R.). Since WW2, this scientific technique has shown itself to be a very powerful method of identifying the inter-relationships between systems, whether technological or even human-based. Mining and its complexities more than adequately lent itself to such investigative methods. Such an investigation should surely have taken place well before attempts were made - on an entirely piecemeal basis - to introduce a completely new technology (at least in the South African mining context) to underground mining.

Only in the latter phase of the introduction of radio to coal mines was any such concerted study of the many issues involved undertaken at all. It was far too late and far too narrowly directed.

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