Conference reports

Military microwaves '80 conference

Cunard Hotel, London, 22nd — 24th October 1980

This three-day event at the Cunard Hotel, London, followed a similar formula to that of the 1978 conference, being combined with an exhibition of microwave products promoted by Microwave Exhibitions and Publishers Ltd., and was cosponsored by the IEE, IERE, EUREL and IEEE MTT Society. The conference was attended by 700 delegates from 30 countries, and the 29-man Technical Programme Committee had members from nine countries.

The Conference was opened by HRH The Duke of Kent, and in his opening address he reminded the participants that electronics, and microwave technology in particular, will assume a dominant importance in the defence world of the 1980s. In addition, he pointed out that, increasingly, the effectiveness of any weapon and the effectiveness of modern combat tactics will depend on the ability to detect, track and destroy the enemy in spite of his best efforts to avoid this process. It depended on the extreme rapidity and accurate exchange of large quantities of information. All these functions — sensing, attacking and communicating — would be impossible without microwaves. He concluded by saying that he welcomed this event both as an opportunity for the services and industry to pick one another's brains and as an admirable shop window for manufacturers of microwave equipment. The conference chairman, Dr. John Clarke, and his Technical Programme Committee had organised an interesting and wide-ranging programme of current military microwave systems and equipment. The programme was in the form of two parallel sessions with principal topics being millimetre waves, transmit/receive devices, communications, antennas and radomes, satellite systems, solid-state technology, electronic warfare, polarisation control, radar, guided weapons, simulators and test equipment.

Millimetre waves

Some of the most informative and interesting papers of the conference were in the millimetre wave area. There were special sessions on circuit technology, target, clutter, propagation and radiometers, all for the millimetre wave region of the spectrum.

In the session on millimetre wave circuit technology there was an interesting juxtaposition of presentations on some of the more important new circuit and transmission line media. M. Inggs (ERA Technology Ltd., UK) described some of the work in the last few years at ERA on dielectric waveguides, in particular performance of active and passive components at frequencies between 30 GHz and 100 GHz. Of particular interest was a complete 90 GHz transceiver circuit fabricated using thick-film techniques. He claimed that at 90 GHz using insular guide (a form of dielectric waveguide) losses of 0.03 dB per guide wavelength could be achieved, and he compared this with 0.1 dB per guide wavelength for FIN line and 0.14 dB per guide wavelength for microstrip on Z-cut quartz. A low-loss transmission medium was considered important to reduce feed-line losses for truly integrated antennas, and some interesting examples of the latter were shown. The dielectrical waveguide was presented as a technology which, if it lives up to its expectations, might produce a relatively straightforward mass-production planar integrated circuit technology.

Equally impressive was the work described in the two papers on E-plane MICs (or FIN line). H. Meinel (AEG-Telefunken, FRG), in a paper entitled 'A survey of planar integrated millimetre wave components', described the performance of a FIN line mounted PIN diode attenuator, detector, balanced mixer and directional coupler. Results were quoted at operating frequency ranges around 30 GHz and 90 GHz, although the author claimed that such devices should have great potential up to 170 GHz. Indicative of the type of performance achieved was the balanced mixer which exhibited a conversion loss of 7 dB (± 1.5 dB) over the band 26.5–40 GHz. The paper presented by R.N. Bates (Philips Research Laboratories, UK) described the construction and performance of E-plane MICs for operation at frequencies up to 100 GHz. A range of components had been fabricated with very acceptable performance. Also presented was a 35 GHz Doppler radar subsystem assembled from various FIN line components, with two separate printed planar antennas.

R.E. Scarman (AEI Semiconductors Ltd., UK) presented performance figures for a 75 GHz and 94 GHz balanced mixer using microstrip on Z-cut quartz substrate. The 75 GHz balanced mixer gave better than 8.5 dB conversion loss over the frequency range 65–85 GHz. The 94 GHz balanced mixer also had a conversion loss of better than 8.5 dB over 91–95 GHz.

High-performance, electronically tunable filters in the millimetre wave part of the spectrum are needed, and M. Lemke (Philips GMBH, FRG), described work on hexagonal ferrite components for use in filters and tunable Gunn oscillators. Bandpass filters had been constructed using 1 and 2 ferrite spheres coupled to an orthogonal crossed waveguide; these 0.5% bandwidth filters were tunable over 25 GHz in the band 50–90 GHz. The combination of the hexagonal ferrite sphere with a Gunn diode oscillator produced a high Q-factor ($Q_0 = 800$) frequency stabilising resonator offering good linearity of tuning centred on 65 GHz.

The session on millimetre wave targets, clutter and propagation was, by contrast, not concerned with the technology of components and subsystems but with the essential parameters of the propagating medium and the targets and their background. The first paper in the session, by B.G. Evans (University of Essex, UK) dealt with the calculation of atmospheric attenuation, crosspolarisation, reflectivity and backscatter cross-section. The mathematical model he presented took a dielectric cyclinder with sharp edges, but could be extended to consider conducting cylinders to calculate other effects such as chaff.

J.J. Gallagher (Georgia Tech., USA) discussed the effects of the atmosphere on millimetre wave systems in comparison with IR, visible and microwave systems. If users required system operation in adverse weather conditions then performance improved in going from IR/visible to millimetre wavelengths and even more at centimetre wavelengths. On this basis centimetre or longer wavelengths would appear to be the most suitable for operation in smokes, fogs and other particulates. However, for some systems aim point accuracy and resolution requirements (0.1–0.5 milliriadians) resulted in impractically large antenna diameters at these longer wavelengths, forcing the use of millimetre waves. His survey of atmospheric effects was supported by reference to experimental work at 94, 140 and 225 GHz.

D. Zur Heiden (Standard Electrik Lorenz AG, FRG)

presented the most interesting paper of the session, entitled '94 GHz radar propagation in a realistic environment'. A 100 ns pulse length radar with a peak power of 1 kW and a 0.07° beamwidth antenna was used to look through an artillery impact area to a corner reflector approximately 2 km distant. The influence of impacting rounds on propagation was found to be low in the millimetre wave region. Attenuation exceeded 15 dB for 0.9 s after detonation; backscatter was equivalent to 14 m² (average) for 1.6 s after detonation. A comparison measurement with an 8–12 mm IR laser showed significantly longer periods of high attenuation.

At millimetre waves steady-state dust and white phosphorous smoke caused negligible attenuation and backscatter. The degradation of millimetre wave radar detection capability in this environment was small. In the highest fire density observed of 4.4 round $s^{-1} km^{-1}$ a reference target could be detected for 91.9% of the total time of the artillery barrage. These figures are useful information on performance of millimetre wave sensors in realistic battlefield conditions, particularly in relation to IR system performance. In addition, if one compares the comparative performance in mist, fog and cloud there is a clear advantage to operating at millimetre waves compared with IR systems, provided that the reduced resolution can be tolerated.

The important and emerging subject of millimetre wave radiometers was dealt with in a special session containing five interesting and varied papers. The measurement results obtained with an airborne high-resolution 90 GHz radiometer were presented by K. Gruner (DFVLR, FRG). His approach was to use a total power radiometer scanning the ground (scan angle ± 14.5°) at 35 GHz, producing 70 lines/s. The system could operate at 84 GHz or 91 GHz with an IF of 1.2 GHz, and it was flown in an aircraft at a velocity of 50 m/s and a flight altitude of 90 m. Radiometric images were displayed as colour pictures on a TV monitor. Excellent quality pictures were shown with a spatial resolution of 1.6 m and a temperature resolution of 0.8° K. So far the measurements had taken place in clear weather conditions, although it was planned to make some runs in foggy conditions.

The most comprehensive study of radiometric target and background signatures was presented by G.R. Selby (EMIE, UK). Using an 81 GHz Dicke switch system he had produced a characterisation of some vehicles in a land background and design rules for the best performance of the radiometer.

Also on the theme of target characteristics, the last paper of the session, by R.H. Dittel (DFVLR, FRG), dealt with automatic identification of targets from passive multifrequency data. Detection and identification of metal targets and the classification of water, ice and snow had been achieved using frequencies of 11, 32 and 90 GHz. It was not clear how much computation was needed to achieve these results nor whether it could be performed in real time, but the work looked promising.

Millimetre wave antennas were discussed in the session entitled 'Special antennas'. N. Williams (ERA, UK) presented a review of antenna types. The printed dipole arrays excited by dielectric waveguide were particularly interesting.

Electronic warfare support measures

EWSM is an area where the effects of security classification have a particularly marked effect on the contents of papers intended for open publication. Nevertheless, the speakers in this session achieved instructive overviews of EWSM systems and components.

R.S. Andrews of Racal-Decca noted that no two users' EWSM requirements would be exactly the same, but they shared the need to warn of hostile radars, measure the direction of arrival and other signal parameters, identify the radar and so set on ECM. Scanning an EWSM system in frequency or space increased the time taken to intercept the radar signal, but improved sensitivity. Even for shipboard EWSM covering 0.5 to 20 GHz some ½ million pulses/s were quite common. Computer-driven EWSM could now give about 2° error in DF. Receiver sensitivity typically needed to be about − 42 dBm for a 20 GHz, 60–70 dBW EIRP threat at the horizon, or about − 60 dBm to allow for over the horizon and sidelobe detection.

According to R. Coppock (GTE-Sylvania) the acousto-optic Bragg cell was rapidly maturing as the major processor for the EWSM signal environment of the 1980s, where an EWSM system would receive several million pulses per second – these would be of many different signal types with many signals simultaneously in each receiver passband. The Bragg cell acted as an optical Fourier transformer, with a resolution proportional to cell aperture length – it could now achieve a bandwidth of 1 GHz about a centre frequency in the range 0.03–4 GHz, a frequency resolution of 1% of the bandwidth, a spurious free dynamic range of 45 dB and a detector readout of 2 μs to 16 ms (though not all simultaneously). The optics represented about 1% of the total system volume and the receiver sensitivity was about −80 dBm.

The advantages of the Bragg cell were nearly unity probability of detection of simultaneous signals, high sensitivity, wide bandwidth, good resolution ($B\tau \sim 1000$) and the ability to process a wide variety of modulations on a monopulse basis. The areas for future device development were improved diffraction efficiency (perhaps 5% within a year), 2 GHz bandwidth, faster readout arrays, increased dynamic range (currently 60 dB) and the development of integrated optics. A 2-dimensional diode array with $B\tau \sim 1000$ would require 10^6 diodes: a readout every 1 μs would imply a 1 THz diode scan rate, though the data array would be rather sparse.

S. Rehnmark (Anaren Microwave) described the development of an impressive 2–4 GHz digital bearing discriminator which used a 16-element Butler matrix fed from 16 tapered slot antenna elements to provide full azimuth coverage and up to ± 60° elevation coverage, with only a 2° RMS bearing error. The design used all 3 outputs from the Butler matrix so as to provide 2 measures of phase and so compensate for phase errors in the system. Anaren was currently using modular concepts to develop a 2-band discriminator that would be only 40 cm diameter and 90 cm high: the sensitivity would be − 60 dBmi over 2–7.5 GHz and − 55 dBmi over 7.5–18 GHz.

J.E. Dean of Filtronic Components outlined some novel designs of highly selective, broadband microwave filters using suspended substrate stripline. Elliptic function lowpass prototypes could be used to provide filters with low loss – however, a generalised Chebyshev prototype (with three transmission zeros at infinity) was nearly as good, but had relatively small impedance variations, which made it more suitable for a stripline implementation. Such filters could achieve insertion losses less than 1 dB and stopband losses greater than 60 dB within 5% of the crossover frequencies for an octave bandwidth passband, and all without requiring any form of tuning.

'Dawn of electronic warfare'

Alfred Price presented a lecture of interest to both the technical and nontechnical alike on the history of electronic warfare. The evolution of countermeasures was traced from its beginning 40 million years ago with bat jamming, through its use in the First World War and then until the end of the Second World War. His main concentration was on the Second World War, and as he pointed out this was the only conflict, so far, in which the effect of electronic warfare employed by

both sides could be analysed. As a result it was possible to examine the influence of electronic warfare not only on the technical but also on the tactical and command aspects of the battle. He described the various systems employed by both the Allies and the Axis powers and their effects and the countermeasures to them. He concluded by quoting Coburn who said of Second World War jamming: 'A pennyworth of jamming will mess up a pound's worth of radar'.

Guided weapons

A.J. Witsmeer (Boeing Aerospace Company, USA) described a most ingenious test chamber for millimetre wave passive seekers. Instead of using an anechoic chamber with walls made of microwave-absorbent material, the solution presented here was to cover the walls, ceiling and floor with highly reflective foil. A skylight provided a view of the cool sky background reflected in a 45° plate; the walls of the chamber appeared at the same temperature as the cold sky background. The reflectivity of the walls was equivalent to -24 dB at 35 GHz. To simulate the hot target signature at millimetre waves, another novel method was used. An array of 1280 household fluorescent tubes placed end-on were lit up according to the temperature required. The plasma in the tubes could be driven to simulate equivalent temperatures to those between 10° K and 500° K. The energy was collimated by placing the tubes in household funnels. This was a neat and relatively cheap solution. This facility is used to test passive seeker performance against simulated target arrays.

Bistatic radar

The Sanctuary experimental bistatic radar employs a co-operative airborne CW transmitter and a ground-based phased-array receiver. The author, F.L. Fleming (Technology Service Corp., USA), said that the motivation for the configuration of this bistatic surface-to-air surveillance and tracking radar was to reduce its vulnerability, especially against attack from antiradiation missiles. The airborne transmitter maintained physical separation from the receiver and operated in locations less susceptible to attack. He pointed out, however, that this bistatic configuration presented severe clutter levels to the receiver. The paper presented resulted from the flight test programme with the airborne transmitter flying at 26000 ft and 460 knots against targets which were A6/A7 jet aircraft flying at 5000–15000 ft and between 300 and 450 knots ground speed. The detection performance and false alarm rate achieved were good. This was a first-rate paper.

Solid-state transmitters

Both ITT, Gilfillan, GE, Syracuse, had papers on power combining of RF solid-state sources. In the first paper, B.J. Sanders of ITT described a 110W parallel plate RF divider/combiner capable of handling 200 kW peak power at L-band. With this he was aiming to produce 100 kW peak power by combining 110 transmitter sources. He justified this approach over a single vacuum tube with the argument that, although initially the solid-state combined approach had been three times as expensive, this had decreased so that they were now comparable. They would have the advantage of high reliability and graceful degradation.

G.B. Sleeper (GE, USA) also discussed high-power solid-state sources. In the L-band radar he described, 50 W solid-state amplifiers were combined to produce an array radar of 44 rows of transmit and receive electronics. In tests over 2 years the radar so far had been very reliable — 3 modules out of 204 failed on average every $\frac{1}{4}$ year test period. M.N. Yoder (Office of Naval Research, USA) presented a paper on the US very

large scale integrated circuits (VLSI) and the very high speed integrated circuits (VHSIC) programmes. He stated that in his opinion these advances were opening new possibilities for radar design, and the advent of the "function on a chip" would enable radar designers to consider new modulation techniques, spectrum spreading and new signal processing techniques which hitherto had been too costly or too bulky.

Microwave tubes

All the microwave tube presentations described efforts to extend the limits of what was currently feasible, namely ultrabroad bandwidth with high power, very high power with good bandwidth, very high frequencies (up to submillimetre) or minute size.

C. Lamesa (Elettronica SPA, Rome) described how the surprisingly simple technique of applying copper metallisation to the beryllium rods supporting the helix in a conventional TWT could control the phase velocity dispersion characteristics. Such modified TWTs could achieve 1 kW peak with a duty cycle of 4% over 2.3–7.5 GHz or over 7.5–17.0 GHz. The authors had not observed an increase in helix losses nor any breakdown problems with sharp metallic edges, and they were now attempting a 10% duty cycle.

V.H. Smith (M−O valve company) reviewed the reductions in the size and weight of magnetrons over the past 25 years, and showed how M−O valve had achieved a 10 W average X-band magnetron that weighed only 50 gm, using Sm-Co magnets. Such magnetrons could operate into a short circuit without damage, and had not yet failed during switch-on from cold. The authors claimed that magnetrons would out-perform semiconductors for at least the next 15 years. Although tubes did have a limited life, they degraded slowly and were not prone to catastrophic failure.

The current interest in the millimetre and submillimetre bands was reflected in two articles discussing the state of the art in tubes and solid-state devices. G. Mourier (Thompson-CSF) presented current research and development on high-power millimetre and submillimetre wave gyrotrons, while K. Amboss (Hughes Aircraft, Electron Dynamics Division) surveyed the current performance of Gunns, Impatts, TWTs, magnetrons, EIOs, EIAs, gyrotrons, peniotrons and ubitrons.

Until a few years ago, output powers of a few hundred kilowatts peak could only be obtained over broad bands by resorting to coupled cavity TWTs. J. Randall (EMI-Varian) showed that the resonant coupled cavity klystron was an alternative that retained the high efficiency, low noise, simplicity and mechanical rubustness of the ordinary klystron. EMI-Varian had achieved 100 kW across an 8% bandwidth with an efficiency of 25%, and had calculated that 12% bandwidth could be achieved.

Antenna arrays

R.J. Mailloux of Rome Air Development Centre, USA, described recent advances in lightweight, lower-cost approaches to aircraft and spacecraft arrays to produce agile, low sidelobe patterns. Typical performance figures sought for advanced scanning arrays were: sidelobes, approximately −50 dB; gain, approximately 40 dB; bandwidth, approximately 12%.

J. James (RMCS, UK) was, on the other hand, at the small-scale end of the field and gave a review of the recent developments and trends in microstrip antennas, considering patch antennas, linear arrays and 2-dimensional arrays, amongst others. His conclusion for patch antennas was that design methods had been established, although more information was still to come on tolerance control, aging and temperature effects. They were ideal for solutions which needed to be of

low cost but with only modest efficiency and bandwidth requirements. G.A. Hockham, in his paper entitled 'Null steering techniques for application to large array antennas', discussed several null steering techniques that could be applied to large array antennas without excessive penalties in system complexity or cost. A dual beam waveguide slotted array structure was described where the nulls were steered by frequency scanning. This was stated to be an efficient antenna for monopulse applications. A large phased array using a series feed system was presented; this operated in the band 3.1–3.6 GHz using 5-bit phase shifters.

Polarisation control

This was an outstanding session ably chaired by Bob Hill. The general aims of the polarisation control of radar signals are the enhancement of the echo strengths of desired targets, the suppression of clutter, multipath or other interfering effects and (possibly) a classification of targets.

A.J. Poelman's (SHAPE Technical Centre) study of controllable polarisation gave a concise review of polarisation fundamentals, and continued with analyses of object scattering, of scalar against vector processing and of adaptive suppression techniques. He concluded that maximum benefit could be obtained from a vector approach in which the transmitted signals provided alternate orthogonally polarised waveforms while the pair of receiving channels were mutually coherent. There were also advantages in the use of virtual adaptive processing where the adaption occurred in the transmit and receive processors rather than at the antenna. Since this polarisation processing was independent of the transmitted waveform, it was not susceptible to exploitation.

N.A. Stewart's (Plessey Radar) measurements at X-band on copolar and crosspolar returns from targets and clutter showed that, when linear polarisation was radiated, there was nothing to be gained from using a second receiver to make use of the crosspolar information. However, his computer simulations based on live radar recordings showed that, with circular polarisation, a second receiver could provide an increase in signal/clutter ratio of 1–4 dB.

D. Hammers (ITT, Gilfillan) provided further evidence of the potential advantages of polarisation control via a computer simulation of the extraction of the returns from a BQM-34A drone from an interfering medium consisting of a chaff cloud modelled as a collection of rotating dipoles. The calculations showed that for a single pulse radar detection probability as a function of the ratio of target to clutter enchoing area, at 5.5 GHz, with a false-alarm probability of 10^{-4}, the performance with optimum dual channel antenna alignment was some 2 dB better than a single channel vertically polarised system. The optimum performance was about 12 dB better than with a horizontally polarised system, but this was largely a consequence of the chaff dipole distribution favouring the horizontal.

This session was completed with two useful antenna papers discussing the realisation of the dual-polarisation capability.

Radomes

A.W. Rudge (ERA) reviewed the field of radome design and performance. Modern trends towards low sidelobe multi-frequency wide bandwidth antenna systems had made radome design much more difficult. A further development had been the move to higher operating frequencies which had exacerbated these problems. For many applications the electrical parameters were only one of the critical factors. In airborne applications, for example, the radome formed an integral part of the airframe. One problem causing the greatest difficulty was that of rain erosion, particularly for vehicles whose operational speed exceeded 100 m/s (250 mph).

D.L. Fudge (MSDS, UK) highlighted one of the airborne radar fields, that of ceramic radomes for guided weapons; The demand for improved missile performance had made radome design more difficult – this was a tradeoff between electrical, aerodynamic and environmental design aspects. He pointed out that, for a tracking antenna, radome-induced errors would shift the null; in a differential system this would have three effects: increased miss distance, reduction in effective range and ECM susceptibility due to increased sidelobes.

The selection of material and electrical design were important in minimising these effects.

Communications

The four papers in this section had little in common apart from their associations with communications: they ranged from guided weapon telemetry and tactical radio relays at UHF to microwave troposcatter links and RPV communications.

The expansion of private mobile radio services in the 1970s forced military telemetry systems to move up from the 430–450 MHz band to a new allocation of 1430–1450 MHz. R.G.A. Marzolini (EMI, Feltham) described how this change, together with concurrent restrictions on the bandwidths occupied by telemetry links, led to the development of the Type 1440 (PAM/FM/FM) system; the parallel development of digital telemetry led to the Type 109 (PCM/FM) system. The change in carrier frequency required the development of new RF units, capable of withstanding the severe missile environment, and included an FM transmitter using phase-lock-loop techniques to achieve stability and spectral purity over a wide temperature range.

The review of 'Triffid – the tractical radio relay for the 80s' by R.I. Dow (Marconi Communication Systems) explained how it had been designed to meet the British Army's requirement for secure trunk communications, while offering ease of operation and maintenance, together with good reliability and EMC. The Triffid equipment (UK/TRC471) had initially been required to operate within the Bruin system, but was intended to convert to the main trunk radio bearer within Ptarmigan; thus, it could handle 250, 256, 500 or 512 bit/s and meet the requirements of either system. Triffid was well into production, with over 70 sets deployed with the Signals Regiments in BAOR, and good reports had been received from operators during Exercise Crusader.

M.R.B. Dunsmore (Royal Signals and Radar Establishment, Malvern) reviewed the design of microwave data links for remotely piloted vehicles. Current research aimed at investigating a range of modulation schemes, from simple broadband FM to fast frequency hopped spread spectrum, and was supporting the development of the specialised components required to push the operating frequencies of RPV data links up to J-band. Hostile ECM could achieve the detection of an RPV data link, and this could be followed by deception or disruption through electromagnetic means, or by physical destruction. However, such threats would be countered by careful control of the power spectral density, spatial spread and time duration of signals transmitted between data link terminals.

Low-noise receivers

This was a particularly well-balanced and instructive session. After an extensive review of future trends in millimetre wave receivers, there were descriptions of recent progress with parametric amplifiers, GaAs FETs and image rejection mixers – the three low-noise receiver technologies that are currently most popular in military microwave systems.

A.G. Cardiasmenos (TRG Division, Alpha Industries)

believed that the next five years would show only modest improvements of perhaps 1–2 dB in room temperature receiver noise figures. By the end of the decade there should be a three-terminal solid-state low-noise amplifier offering 10 dB gain and 4 dB noise figures at about 100 GHz, and monolithic technology should be heading towards 1 THz. The millimetre wave market was currently influenced mainly by military requirements, but the millimetre wave sphere required an infusion of money from outside the military domain. Domestic broadcast satellites would gradually become a major market trend.

The principal areas of future low-noise millimetre wave developments would be an increase in operating frequency to 230 GHz, thermoelectrically cooled receivers with low-noise FET IFs, reduction in size and weight and optimisation of designs for cost-effective mass production.

L. Fowler described the construction techniques used in two recent X-band parametric amplifiers developed by Ferranti Electronics for demanding military radar and satellite communications applications. The military radar paramp provided a noise figure of less than 2.2 dB with 15 dB of gain over a broad, flat passband; the gain stability was better than ± 0.3 dB over the full military temperature range and several amplifiers of this type had shown a gain stability of better than ± 0.5 dB over an 8000 h period. The Sat Com paramp was assembled in a hermetically sealed package with an integral power supply, and was believed to be the smallest militarised paramp available.

Designers of low-noise amplifiers frequently have to provide excellent electrical performance while withstanding a rigorous military environment. J. Arnold (Plessey Research) believed that customers for ruggedised GaAs FET amplifiers preferred straightforward designs. Complex circuitry could be more compact, but it sometimes resulted in poor yields and inferior performance. The ultimate performance in FET amplifiers would always be achieved with chip devices, though this required hermetic sealing of the complete amplifier. Burn-out resistance up to 20–30 W peak for pulses of a few nanoseconds required careful visual inspection of chips to eliminate those with obvious defects.

E. Smith (AEI Semiconductors) discussed the construction of image rejection mixers and the use of automatic test equipment during their production. The double balanced mixer configuration provided a noise figure of 6.0 dB over a 10% bandwidth at X-band, while the double ring mixer could achieve 5.5 dB over a 15% bandwidth together with 20 dB of image rejection.

Transmit-receive devices for radars

One of the major difficulties in any radar design is the protection of the sensitive receiver from the high-power transmitter pulse. Four of this session's papers addressed the design of limiters and circulators; the fifth provided a novel solution to antenna siting problems on board ships.

Every ship-borne microwave system ideally needs to have its antenna located on top of the highest mast. Since this cannot be achieved we have problems of mutual obscuration with a resultant increase in sidelobe levels and hence vulnerability to jamming. B.E. Kruger presented the ITT (Gilfillan) alternative to phased arrays, namely the 'Unimast' concept in which the antenna revolved round the mast; however, this concept required a wideband, high-powered annular rotary coupler. This could be achieved by using a coaxial, equal line-length feed in concert with an effectively continuous annular waveguide structure for both the rotor and stator.

P.N. Walker presented a review of Ferranti's work on high-power junction and differential phase-shift circulators. By operating low-line width ferrite material between the main and subsidiary resonance regions, energy was not lost from the uniform resonance of the ferrite to other spin-wave states. Thus, low losses could be achieved at both low and high power levels. For example, waveguide junction circulators with composite turnstile resonators had been tested to 400 kW peak at 3.0 GHz and 6.5 kW CW at 2.35 GHz.

The usual lifetimes of receiver protection devices made them seem like consumable items rather than part of the system hardware. However, the externally driven PIN diode device described by A.W. Robinson (EEV, Lincoln) had a predicted life of more than 10^4 h, and had resisted 20 g shocks and -10 to $+70°$C temperature variations. In addition it provided insertion losses less than 0.4 dB and isolation approximately 70 dB across a 300 MHz bandwidth at S-band, while resisting 900 W mean at pulse durations up to 20 μs (50 kW peak). This appeared to be a useful and worthwhile approach when passive protection was not required. The use of PIN diodes in units giving passive protection was described in another paper by C. Hamilton (AEG – Telefunken), and the penalty of increased insertion loss was freely admitted.

Radar test equipment

The session on radar test equipment reflected the current trends towards simulation and automation, as ways of reducing the development and production costs that can arise from system trials or the use of skilled engineers to supervise routine measurements. This is a subject that is rarely covered in conferences. The equipments described were, of course, more complex and specialised than routine computer controlled laboratory systems.

G.H. Swallow (GEC Hirst Research Centre) reviewed the stages in the design and construction of an S-band acoustic wave delay line, from the NC milled aluminium box to the completed unit. The pulse delay was 22 μs with an overall attenuation of 65 dB $\pm$ 1 dB (over all conditions). This device had been fully qualified for operation in the military environment and although unusual would undoubtedly find significant system applications especially for built-in test purposes.

For many years engineers have tended to avoid making measurements of noise spectra on microwave carriers since such measurements were difficult, tedious and prone to error, especially if the microwave test set was not designed and operated by an experienced engineer. W.J. McClintock (Marconi Research Laboratories) described an accurate 2-4 GHz carrier noise analyser which would enable such measurements to become routine tests on production lines. The use of a desk calculator to control the measurement process minimised the risk of errors, allowed the use of semi-skilled staff, reduced testing time and improved accuracy (by incorporating statistical averaging techniques in the measurement process). The system could be adapted for measurements at other frequencies by changing the microwave circuitry. The CNA allowed sidebands to be measured with an accuracy of $\pm$ 1 dB down to 140–160 dB/Hz below carrier over a frequency range of 50 Hz–5 MHz for all types of noise measurement, except for source FM where the threshold rose by about 25 dB/decade below 100 KHz.

Radar instrumentation

This session contained two papers on the simulation of radar threats, one on a Doppler system for measuring projectile miss distances and one on the measurement of radiation scattered back from scale target models.

G.D. Hawkins (Walmore Electronics) described a computer-controlled system that could provide aircrews with a realistic and accurate simulation of the electromagnetic environment

created by the density and types of radars likely to be encountered in actual combat. This simulator could be assembled from a series of modules linked to a 32-bit parallel data bus. The capabilities of the system varied with the numbers and types of modules selected. For example, the four frequency modules provided frequency coverage from 2 to 18 000 MHz, and included a frequency synthesiser that could generate up to 256 signals with a tuning and lock time of $4\,\mu s$; other modules simulated the antenna scan and pulse repetition characteristics of radars. RAMs in the modules could be preloaded, via the bus, with emitter details, and these details could be amended in real time by an instructor.

W.T. Harpster (Emerson Electric) noted that in any future hostilities a significant proportion of aircraft attacks would have to be conducted in areas heavily defended by radar controlled air defence missile and gun systems, and that realistic pilot training could not be accomplished without a reasonable simulation of this threat. The Emerson Tactical Radar Threat Generator provided a dual simulation by radiating a signal that would be detected by an aircraft's radar warning receiver as if it had come from an enemy threat system, while simultaneously presenting the TRTG operator with details of aircraft hits resulting from simulated firing of the threat system.

When missiles are fired during equipment development or for military training, miss distances of a few metres may have to be measured at distances up to ten kilometres — without affecting the operation of the weapon system. Mrs. L.I. Ruffe gave a fluent description of how Racal-MESL had developed a homodyne Doppler miss-distance radar that could be carried on the target itself. Only a minimum amount of processing occurred on the target before data were telemetered to the ground using frequency modulation of the radar transmissions. Detection of a projectile, and computation and display of the miss distance were all performed automatically, so that the ground equipment did not require skilled operators. Mrs. Ruffe concluded her presentation with a film of the miss distance radar in operation with a Blow-pipe missile fired at a Snipe drone and a naval 4.5 inch gun fired at a towed Rushton target.

Conclusion

Overall, the 1980 military microwaves conference must be rated a well-organised success. The coverage of current microwave technology was extensive, with several papers on advances that have not featured in the conference scene, for example the Sanctuary radar performance, low-mass membrane antenna, and new digital bearing discriminators. Also, the coverage in the session on polarisation control as a method of improving radar performance was unique. The sessions on millimetre wave systems and technology were particularly informative, and well timed in view of the current interest in millimetre wave applications.

M.R.B. DUNSMORE
S.E. GIBBS
RSRE, Malvern, England

NATO Advanced Study Institute on signal processing: underwater acoustics

Lyngby, Denmark, 18th—29th August 1980

The conference was in two parts: the first, of three days, related to physical acoustics, and the second, of seven days, was mostly devoted to signal processing theory and practice.

Physical acoustics: The first part was of rather specialised interest to those active in acoustics, with discussions of noise generation in the oceans by ships, machinery, ice and biological sources, its subsequent propagation in bounded inhomogeneous media, and finally its absorption by the action of dissolved salts, the sea floor and biological matter. An interesting gulf between those who treat the ocean parameters as stochastic variables and those who model them as determinate became apparent, and there is clearly a lot of work to be done before a unified description of the oceans can be formulated and used for acoustic predictions. A number of papers on acoustic transducers were presented in this section, perhaps the most interesting being one by Folds (NCSL), containing a description of an acoustic zoom lens to focus from 10 to 150 m at around 860 kHz with a triplet lens at one end, and doublet at the other, a solid movable zoom element, and an aperture of about 1 m. The purpose of this structure was not revealed.

Estimation and detection theory: The second part, dealing with estimation and detection, is of interest to a wide field of workers. The major applications discussed seemed to relate to passive sonar, where the task is initially to detect a noise source, i.e. a moving vessel, in the presence of background medium noise, interference from shipping, and self noise, and secondly to estimate parameters of the source — bearing, range, and velocity vector — and frequency spectrum for classification purposes. The data rates are often quite low, allowing online processing to be developed to a fine art, and sophisticated algorithms for data reduction based on conditional probabilities, least squares, and principal component analyses were very much in evidence. The problems tackled would, in the absence of the medium and interference, be reasonably straightforward, but the multimode fluctuating propagation paths, interference, and sometimes even uncertainty about the shape of the receiving array combine to make a nonsense of classical textbook methods.

P. Schultheiss (Yale) discussed the application of the Cramer-Rao bound to parameter estimation and the problem of determining the arrival times, at an array of hydrophones, of a broadband signal. Given these, one can determine bearing, range (from wavefront curvature) and velocity of a source, but the results are often ill-conditioned and ambiguous. It is important to have a theoretical estimate of performance limits, and the Barankin bound was proposed as more suitable than the Cramer-Rao. N. Owsley (NUSC) also addressed the time-of-arrival problem, and used the maximum *a posteriori* parameter estimation (MAP) strategy to estimate either source location or array shape. The MAP estimate is a maximum-likelihood estimate modified to incorporate *a priori* constraints on parameters set by the physics of the problem. The multimode propagation models treated were: (i) single path with incoherent wavefront, (ii) dual paths uncorrelated in the time domain but spatially coherent, and (iii) dual paths with time correlation. Van den Bos (Holland) tackled a more abstract problem: that of estimating parameters when the observations are nonlinear functions of them. The minimisation of mean-square error or other criterion involves the use of descent techniques unlike standard least-squares problems, which are

solved essentially by sample matrix inversion. Some difficult convergence problems arise, and the use of a gradient technique intermediate between Newton-Raphson and steepest-descent was advocated (Marquardt's algorithm).

The use of principal component analysis for detection and estimation seems to be growing in popularity. Bienvenue and Kopp (France) described how the eigenstructure of a narrow-band covariance matrix could be used to identify the subspace spanned by multiple plane wave signals and how the source directions could thereafter be inferred. Better resolution than 'optimal beamforming' was claimed. Other eigenvector techniques were described by Pignon (France) and Böhme (Germany).

Spectrum analysis methods: E. Parzen (Texas A & M University) surveyed the field of model fitting, e.g. AR models, whitening filters, minimisation of entropy distance, and log spectral smoothing, while Frost (USA) described the extension of the predictive data extrapolation technique to two-dimensional spectra, typically spatial-frequency/angular-frequency plots, and the problems encountered. Improvement in resolution by a factor of four was observed in certain data. Some of the other topics covered were the tracking of multiple sinusoids in noise (Scharf, USA; Chan *et al*., Canada), the detection of nuclear explosions and filtering from seismic noise (Ives,

USA), and the effects of AGC on parameter estimation with fluctuating signals (Picinbono, France).

Adaptive beamforming: B. Widrow (Stanford) gave an overview of the subject which seems to be emerging from the laboratory into the field with several papers reporting realistic simulations. Gammelsaeter (Norway) has modelled many practical effects in simulation, and reports the effects of pointing errors, finite bandwidth, wavefront incoherence, array errors, and some suboptimal implementations. Durrani (Strathclyde) and Cantoni (Australia) discussed broadband adaptive beamformers with rapid convergence, the former using constrained lattice filters and the latter a recursive Kalman-filter-like algorithm.

Other topics included sound channel modelling (D. Middleton, New York), digital hardware for vector processing, hybrid SAW/digital circuits, two-dimensional digital filtering, radio astronomy imaging, and seismic data analysis.

In all, some 43 papers were devoted to signal processing and the proceedings should be a fruitful source of ideas for people with problems in related areas. They will be published by Reidel early in 1981 under the title: 'Underwater acoustics and signal processing'.

J.E. HUDSON
Loughborough University, England

Abstracts of papers published in other Parts of the *IEE Proceedings*

The following papers of interest to readers of *IEE Proceedings Part F* have appeared in recent issues of other Parts of the *IEE Proceedings*:

Design method of multistage amplifiers using Nichols chart
PROF. YOSHIHIRO MIWA

[*IEE Proc. G, Electron, Circ. & Syst.*, 1981, **128**, (1), pp. 1–8]

A method for the graphical analysis of various characteristic quantities of active two-port networks, using the Nichols chart, is given. A method of graphically designing high-frequency multistage amplifiers using this graphical analysis method is described. The multistage amplifiers can be designed in the same way if any one of three stability factors (invariant stability factor, Stern's stability factor and performance factor) is specified. One can design these amplifiers using only two charts (the Nichols chart and the auxiliary curves overlay) without using many graphs. This method is very convenient in the design of multistage amplifiers using potentially unstable active elements.

Paper 960G

Simple, wide-range approximations to trigonometric and inverse trigonometric functions useful in real-time signal processing
E. SEEVINCK

[*IEE Proc. G, Electron, Circ. & Syst.*, 1981, **128**, (1), pp. 41–4]

By means of straightforward methods, simple approximations are derived for the cosine, sine and tangent functions as well as for their inverse functions. The approximations are simple in the sense that they contain few terms and have numerical coefficients with, at most, three significant figures. The trigonometric approximations presented are valid in all four quadrants, including the singularity points in the case of the tangent. The inverse trigonometric approximations are valid over the full natural argument intervals. The absolute approximation errors are shown to be near-minimax with peak values all less than 0.25% of maximum. The results are expected to be useful in real-time signal processing circuits and systems where speed and simplicity rather than extreme accuracy are the dominating factors. A translinear circuit realisation example is given in the Appendix.

Paper 1036G