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A Comparison of the Use of Analogue and Digital Integrated Circuits in Sonar Systems.

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Introduction.

At present an integrated circuit is only economic when it is mass produced. The cost of art work alone for quite simple thin-film or thick-film circuits is quite staggering. The hybridisation of monolithic and either or both of the film technologies to create special "low-run" circuits is uneconomic while the cost of art work remains high. Computer aided design techniques with automated art work machines (1) are already available in some organisations. One day these facilities should be available to all just as computer time can be purchased now. For the present though, it is still feasible to use discrete devices, together with integrated mass produced circuits in the design and manufacture of sonar signal processing systems.

Brief Survey of Digital Microcircuits.

Much initial effort went into the development of digital integrated circuits for use in space and computer technoligies. Early circuits were usually copies of those which could be made using discrete components, and indeed, this is still partially true today. One major exception was the introduction of a multi-emitter transistor as the gating device, and the resulting transistor-transistor logic (TTL) circuits are very popular. In the U.K. in particular, the 74 series of these TTL devices is marketed by many manufacturers, and with increasing popularity this series is now very competitive with the slower diode-transistor and resistance-transistor logic families. Compatibility, both electrically and mechanically between devices made by different manufacturers is an important factor when deciding which family of circuits to use.

Increased scales of integration have been modest when using bipolar transistor circuits, and the metal-oxide-semiconductor type of device has led the way in large scale integration techniques. Here, because of expensive art work, it is important to have large production runs to produce an economic device. Large scale integration devices for civil applications are still too expensive for many without their own in-house production facilities. Indeed apart from such circuits as the digital correlator (2) large scale integration progress has been rather disappointing in sonar development work.

For higher speeds, non-saturating emitter-coupled logic flip-flops, with toggling rates of 100 MHz are available for about twenty shillings. If faster speeds are essential, and finance available, designers can call upon devices with propagation delays less than 3 nanoseconds, and flip-flops can be made to run at toggle rates up to 350 MHz. The future limit in speed would appear to be created by power dissipation and interconnection problems (3).

The State of the Art in Analogue Integrated Circuits.

The operations required for sonar signal processing units are those of adding, subtraction, modulation, multiplication, amplification and frequency filtering. The first three of these operations are those encountered everyday in the analogue computer field, and, within the limits of frequency response, may be achieved using integrated circuit operational amplifiers. These are now highly developed, and several so called generations exist. Many manufacturers make electrically and mechanically compatible circuits, and in this respect the integrated operational amplifier is similar to many digital microcircuits.

Several integrated modulator circuits exist, and as with all components as their popularity has increased their price has fallen. Now, for example, a balanced integrated modulator which gives signal and carrier rejection levels of at least 40 dB can be bought for one or two pounds sterling. Even with discrete components, the design of a good linear multiplier with a good dynamic range was very difficult. Integrated circuit technology could to a certain extent help to solve the problems which are mainly those of matching components. It is therefore surprising that integrated multipliers have only just become available, and these still need resistance trimmers to achieve zero offsets. One such multiplier has a double ended output, and needs an operational amplifier to obtain a single ended output. The manufacturers claim that it is the operational amplifier which limits the frequency response.

Integrated amplifiers are available in many configurations. The cascode configuration is quite popular, and many integrated amplifiers are based on this. The noise performance of this configuration is claimed to be the best that can be obtained for a two stage amplifier using integrated bipolar transistors[4]. Its noise performance nevertheless falls short of that which can be achieved using discrete low noise bipolar transistors. In the integrated cascode amplifier gain can be controlled by varying the operating current of one or both of the cascoded transistors. With the correct choise of automatic gain control components over two cascode amplifier stages, an input signal with a 60 dB dynamic range can be compressed to about 10 dB, the dynamic range of most cathode-ray tube displays.

Filters are very difficult to realise in microcircuit form at the normal frequencies encountered in sonar processors. A first step towards microminiaturisation is to replace capacitance-inductance circuits by capacitance-resistance active filters[5]. In the communications field active filters are used which are hybrids of film and monolithic technologies[6]. In sonar work standardisation of filters is nearly impossible because each system has different specifications. A step towards standardisation would be to adopt some amplifier configuration embedded in CR elements to give the correct transfer function. The amplifier would be standard but the CR elements would be non-standard. N-path filters[7] could also solve this problem particularly if linear integrated multipliers become cheap[8]. The N-path filter is very attractive since it can be tuned by an externally injected signal.

Comparison of digital and analogue integrated circuits in sonar.

Very often it is possible to perform a particular signal processing operation by using either analogue or digital techniques. A general principle is that the designer should choose the system which can be most easily implemented, and usually this is also the cheapest.

Consider a simple pulsed sonar system which gives both range and bearing information, where bearing information is gained entirely from the phase of the received signal. Since this can be obtained from zero-crossings of the returning pulsed carrier signals, the signals may be hard-limited immediately after reception. The processor then operates upon signals which are essentially binary, and it would seem obvious to use a digital processing system(9). However the processing may be carried out using analogue techniques(10). The fact that the digital processor could use mostly integrated electronics reduces costs and the digital processor seems to have prospered(11).

In a within-pulse scanning sonar, the scanning mechanism mathematically carries out a Fourier transform(12). The Fourier Transform may of course be obtained from either a digital(14) or analogue(13) processor. Even the fast Fourier transform (FFT) algorithm cannot reduce the time required to carry out the transform indefinitely, and in some instaces a digital realisation may provide insufficient range resolution. One solution to the analogue type of Fourier transform machine is to use modulation and remodulation techniques(15), and with the availability of reliable balanced integrated modulators this solution is very attractive.

Where high resolution is not required, the availability of FFT hardware(16) which can be coupled to a digital computer may decide the designer to use digital techniques. This is particularly advantageous, if he requires a versatile system which can be converted quickly, to give for example doppler information(17). In any case a study of the FFT algorithm can enable the switched beam type of system to be realised in analogue form using less components.

Conclusions.

No doubt there will be many changes in the future, and it is difficult to look far ahead. Claims have been made that tristable circuits could increase processing speeds,(18) and if devices of this type should become available our ideas of today could be completely changed. Analogue integrated circuits will become more versatile, more varied in the operations they can carry out, and with their increasing use their price will become reduced. Perhaps even increased scales of integration will occur in analogue microcircuits.

Any predominance of either digital or analogue microcircuits will depend upon how the semiconductor industry stabilises. It can stabilise on the product, in which case digital integrated circuits, which need few if any additional components, will probably dominate. However should the industry stablise on the process, complete integration, using hybridsation of monolithic and film technologies, would become available to all. Under these circumstances, neither analogue nor digital components would be dominant.

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