Capturing and Creating X Band Pulses

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This paper describes some of the problems encountered, and the solutions adopted in the design of a Racon (figure 1). There are many challenges to be overcome during the design of a racon. A few, which have a wider application and thus may be of interest to a more general audience are presented here.

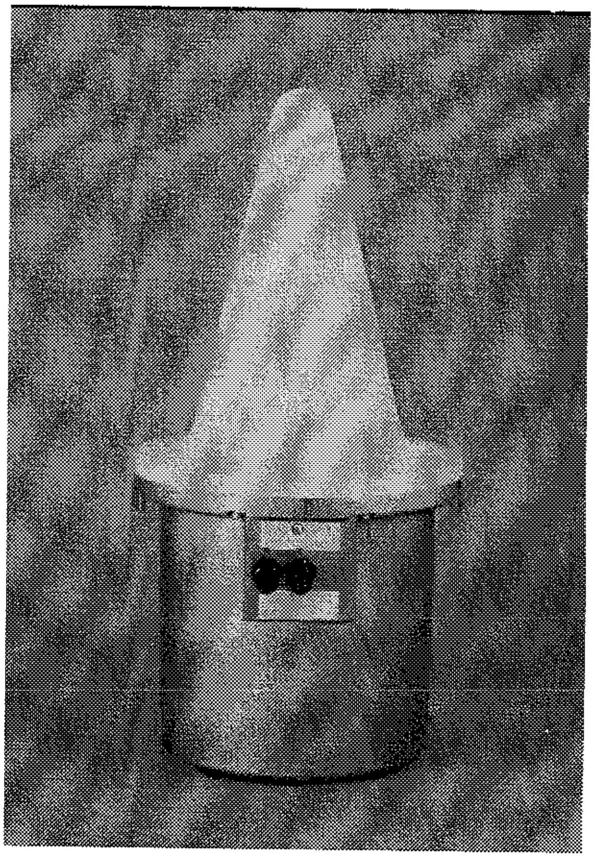


Figure 1 Phalcon 2000 Racon

A racon is a frequency agile radar beacon that transmits in response to signals from marine radars. It operates in the 10cm, S band (2.9 - 3.1GHz) and the 3cm, X band (9.3 - 9.5GHz), although some X band only units are deployed in areas of low activity. The racon transmits a coded reply in response to any valid radar signals it receives. This coded response is in the form of a Morse code character that is displayed on the radar screen indicating the its position. (figure 2)

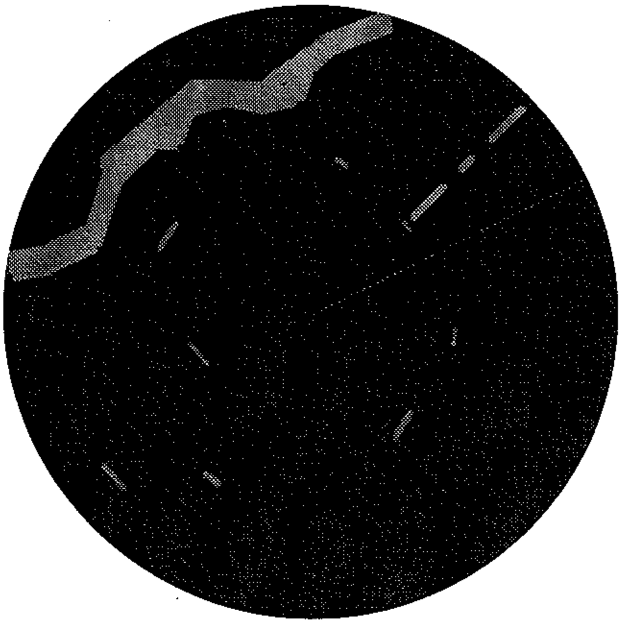


Fig 2. Radar display showing a racon

Racons are generally used as passage markers or to mark shipping hazards As such they can be deployed in remote locations such as on buoys where the only source of power is a solar recharged battery. It goes without saying that in such circumstances reliability has a very high priority in the design process. However power consumption is also a very important issue and is more immediately visible to the user. An abridged racon specification is shown in table 1.

PARAMETER	SPECIFICATION
Frequency range	
X-band	Min/max. 9300 to 9500 MHz
S-band	Min/max. 2900 to 3100 MHz
Frequency matching accuracy	
Radar pulsewidth <= 200 ns	2 MHz
Radar pulsewidth > 200 ns	1 MHz
Output power to antenna	X-band 1.0 W min. S-band 0.5 W min.
Response delay	0.53 µS max.
Response rate	10,000 pulses per second
Response period	Up to 48 µS (total code length)
Racon response scaling	Automatically variable 0.16 to 2.0 NM dependent on interrogating radar pulse length
Sensitivity	
X-Band	-40 to +20 dBm, programmable
S-Band	-40 to +20 dBm, programmable
Antenna polarisation	X-band horizontal S-band horizontal & vertical
Antenna gain	X-band 4 dBi S-band 2 dBi
Temperature range	-40 to +70 deg c

Table 1 Racon specification

The racon classifies signals received from radars within its service area in terms of frequency, amplitude and duration to determine their validity. Replies are inhibited for pulse widths greater than 2us and frequencies received from outside the recognised radar bands. Replies are also inhibited if signals are been identified as coming from the antenna sidelobes of previously classified radars.

The radar's transmitted pulse width is varied according to the range scale set on the display, with pulse widths of 50ns used for short range and up to 2us for long range. The racon reply is scaled according to the received pulse width such that the 'paint' length on the radar display remains constant.

IMO (International Maritime Organisation) requirements state that the racons indicated position must be displaced by less than 100 metres from its true position. This allows less than 600ns from the reception of a radar pulse for all measurements to be completed, and the transmitter to be enabled prior to transmitting the reply. IMO regulations also stipulate that the tracking accuracy for radar pulse widths of greater than 200ns is to be better than 1.5MHz and for pulses less than 200ns, better than 3MHz. However commercial considerations and customer expectation demand that the tracking accuracies are better than 1MHz and 2MHz respectively.

The sensitivity, and thus working range of the racon can be adjusted by the user to suit local circumstances. To give a range of 40km, the maximum at which a racon would normally be visible to a shipbourne radar, requires a sensitivity at X band of -40dBm. At first sight this sensitivity specification does not seem to be particularly onerous. However when combined with a frequency matching accuracy (the allowable error between received signal and transmitted signal) of less than 1MHz then it becomes clear that the accurate frequency measurement of short pulses is going to become an area of major risk in the design.

During the initial feasibility study,digital sampling and replaying via a circulating memory was investigated. This technique is used in some military jamming equipment where highly accurate reconstruction of the incoming pulse is required. It would have the advantage that frequency matching accuracy would be in the kilohertz region, but a 200MHz bandwidth would have to be sampled and reconstructed. At the time they were investigated the high speed analogue to digital converters, memory and digital to analogue converters capable of operating at the necessary speeds required more power than was available. Further, although the technique is suitable for a jammer replaying a near exact replica of the incoming pulse, significant further processing is required to enable pulses of differing lengths to be generated with minimal spurii, and also to remove the effects of varying input signal strength.

Another technique widely used in electronic warfare to measure the amplitude and frequency of short duration pulse signals is to use an instantaneous frequency measurement receiver (IFM) and a detector log video amplifier (figure 3). The ability to accurately measure frequency is dependent upon the output stability of the limiter and any noise on the video output.
It was decided that since reducing power consumption was more important than perfect frequency accuracy, that the traditional IFM receiver approach should be pursued.

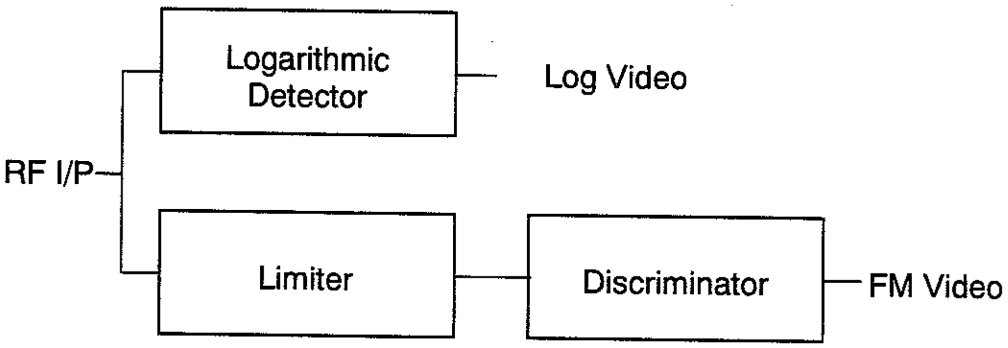


Figure 3 Instantaneous Frequency Measuring (IFM) Receiver

Digital sampling	IFM
Good frequency matching	Frequency matching not ideal
High power consumption	Low power consumption
Mixer TX needed, Spurious outputs	Simple transmitter
DSP	Limiter + discriminator & feedback loop

Table 2 Comparison Between Digital and Analogue Approach

The discriminator usually employs a delay line as the frequency determining element, (figure 4) and in some systems two mixers are arranged to give an in phase and quadrature (I & Q) output to improve frequency resolution. Only one output has been used here to conserve power. The frequency at which the processing is carried out can be either the signal frequency or a convenient intermediate frequency. Operating at the signal frequency was chosen to save the cost and power consumption of a down converter, and also to minimise any bandwidth restrictions which could compromise the fidelity of short pulses.

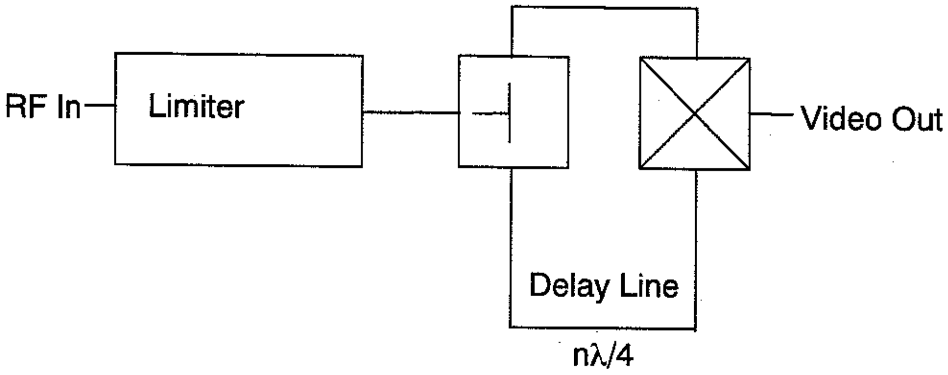


Figure 4 Delay Line Frequency Discriminator

60dB Dynamic Range
Output Power Independent of Input Level
<30ns Minimal settling Time
Low AM-PM Conversion
Temperature Stable Output

Any variation in level affects the reported frequency

Table 3 Limiter requirements

also recovers from pulse

60dB Dynamic range
Fast rise and fall times
Short settling time
Accurate logarithmic transfer function

Table 4 Amplitude detector requirements

Table 3 summarises the requirements for a limiter to be used in a delay line discriminator and Table 4 summarises those for the amplitude detector. Any variation in limiter output level during the pulse has an adverse effect on the reported frequency. Of particular importance is the settling time of the output. The input pulse width can be as short as 50ns, and to be sure that the signal is sampled before any turn off transient effects in the interrogating radar, the signal is sampled at approximately 30ns after the leading edge. This calls for the limiter, discriminator element and video amplifiers to have settled to better than 0.5% within 30ns.

Similarly the amplitude detector pulse response must have a fast rise time and have settled within 30ns to allow accurate amplitude measurement of the input signal. An accurate logarithmic response is needed over a 60dB dynamic range to allow for sensitivity adjustment and the operation of sidelobe suppression when a vessel is passing close by to the racon.

At intermediate frequencies it is common to combine the functions of the logarithmic detector and limiter by using a successive detection log amplifier, where the saturation currents of the amplifier stages are used to form the logarithmic detector function. To minimise the number of active stages and thus keep power consumption to a minimum, such a circuit was investigated. A successful circuit was developed, but it needed very careful adjustment to achieve a useable log response. The compromise between the biasing requirements of the FETs for minimising output level variation, and the biasing required for an optimal logarithmic detector transfer function made the circuit very difficult to set up. This led to the final design separating the limiter and log detector functions to allow the operating parameters of each circuit to be optimised. The decision did not affect the overall power consumption significantly, but did increase overall unit size slightly and the slightly greater number of components has an adverse effect on the calculated reliability.
For amplitude detection a conventional extended range detector log video amplifier optimised for low power operation over the frequency range of interest was used, figure 5 shows the configuration.

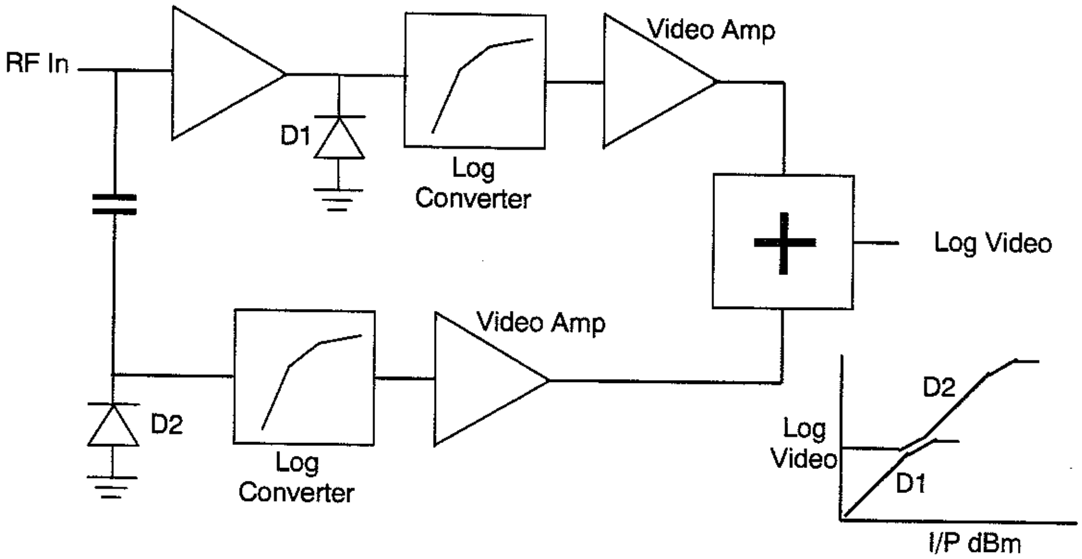


Figure 5 Extended Range Detector Log Video Amplifier

In this design D1 which follows the RF amplifier is able to detect low level signals, up to about -10dBm input. And D2 which has no preceding amplification detects higher signal levels up to +20dBm . The outputs of the two diodes are passed through a logarithmic function and are summed to form a single detector covering the full dynamic range.

During commissioning of the system some unexpected serious frequency matching errors were observed when responding to X Band pulses. Initial investigations found that the pulse response of the discriminator had apparently **been** set correctly. This was corrected and the receiver replaced in the system; there still remained an unexplained frequency matching error. The transmitter short term frequency drift was checked using the discriminator in the receiver and found to be acceptable. From these measurements it was concluded that the most likely source of the error was outside the racon; either the signal generator or the spectrum analyser. The signal generator cw output was found to be within a few kHz of that indicated by the spectrum analyser. Perhaps pulse modulation was having some transient effect on the signal generator.

It was thought that a possible cause of the problem was incidental FM, noticeable on short duration pulses using a spectrum analyser as an asymmetry in the spectral lobes. This it was believed was being caused by the PIN diode modulator used in the signal generator. Figure 6 shows the output spectrum of the signal generator while generating a 100ns pulse, and figure 7 shows the racon response to the signal.

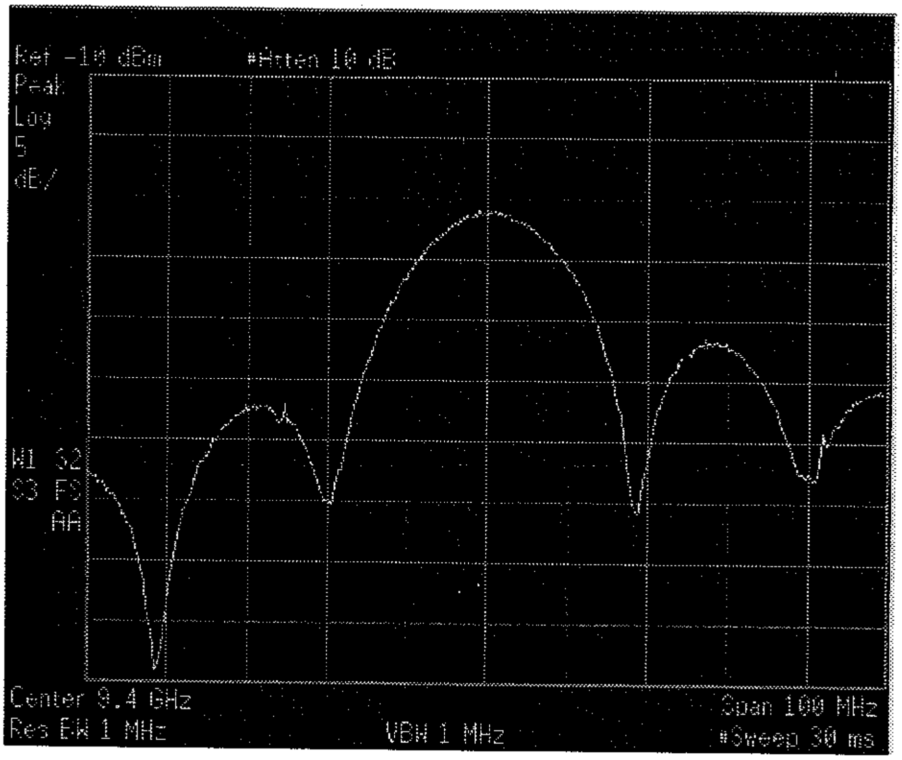


Figure 6 Pulse Spectrum of Signal Generator

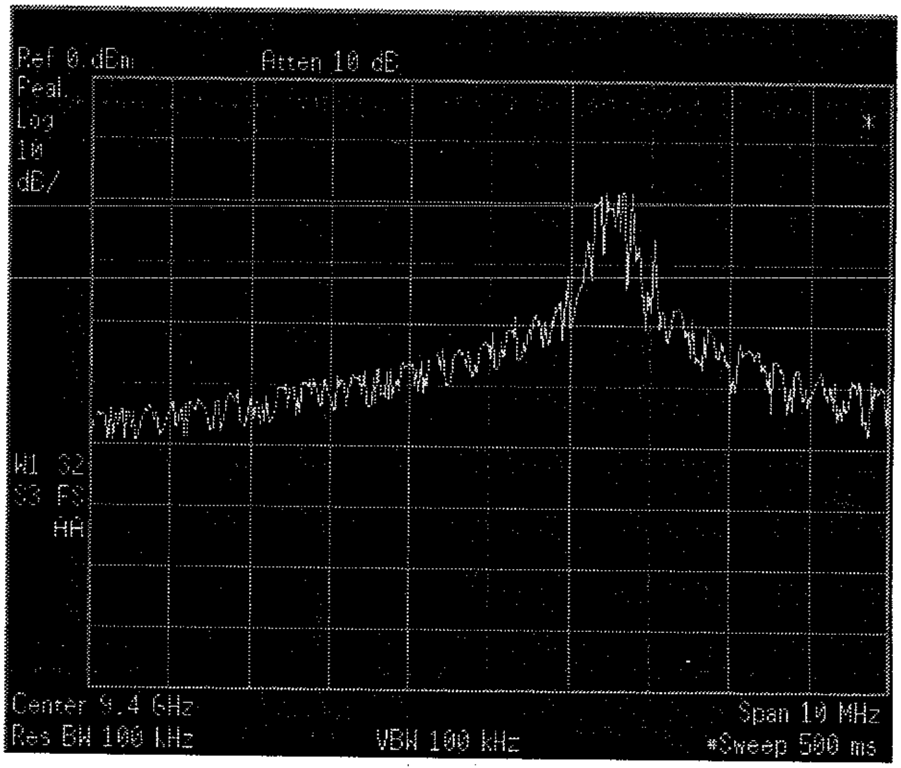


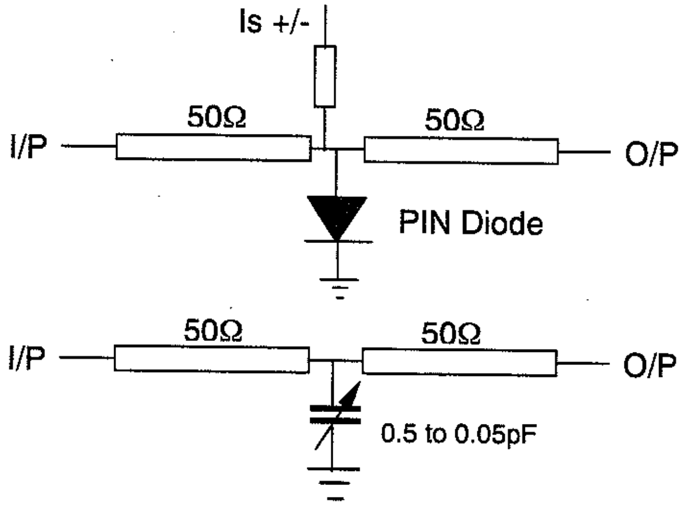
Figure 7 Racon Response to the Pulsed Output of the Signal Generator

Should be here.

Phase modulation during the transition between on and off states of a modulator can only be eliminated if the angle of S21 remains constant before, during and after the transition, an unlikely occurrence at high frequencies. In any modulator there will be phase modulation during the transition between on and off states. The best that can be achieved is for the phase angle to stabilise in as short a time as possible.

Ideally the phase modulation reduces to negligible proportions as soon as the amplitude has settled. At frequencies in the X band this has been observed not to be the case.

As an example considering only the change in capacitance of a shunt connected PIN diode(figure 8) as it turns off. A change in capacitance from 0.5 to 0.05pF gives a change in group delay of 6.5ps at 10GHz if this change were to take place over 25ns it would give rise to a frequency deviation of 2.6MHz. A serious source of error when trying to verify a tracking accuracy of 2MHz.



$$\Delta F = \frac{6.5\text{ps}}{100\text{ps} \times 25\text{ns}} = 2.6\text{MHz}$$

Figure 8 Incidental FM from a Shunt Connected PIN Diode

To investigate this a pulsed signal source was constructed (figure 9). Initially the internal pulse modulator in a low frequency signal generator was used but this was unsuccessful in producing a pulse with a fast enough rise and fall times to generate a 50ns pulse.

For production testing of Pascall's IF components a proprietary external pulse modulator is used. These are based on FET switches and give pulse rise and fall times of approximately 2ns. At the time these test were being carried out no suitable modulators were available, so a modulator was constructed from readily available parts.

The design required high isolation and fast switching speed. A shunt diode configuration was chosen as being the most suitable (figure 10). Instead of the more usual PIN diodes being used as the switching element Schottcky barrier diodes were chosen. Having no intrinsic region to discharge, these diodes can be switched from on to off state at least an order of magnitude faster than a PIN diode. It is however important to ensure that sufficient bias voltage and current is available to prevent the diodes from rectifying the RF waveform and reducing the on / off ratio. Using this as a signal source reduced the frequency matching errors to expected levels showing that the pulsed microwave signal generator had been a major contributor to the errors seen when initially commissioning the racon.

This signal source was adequate to prove that the original signal generator was unsuitable for testing the racon, but suffers several drawbacks when used in a production environment, not least of which is the requirement for two signal generators.

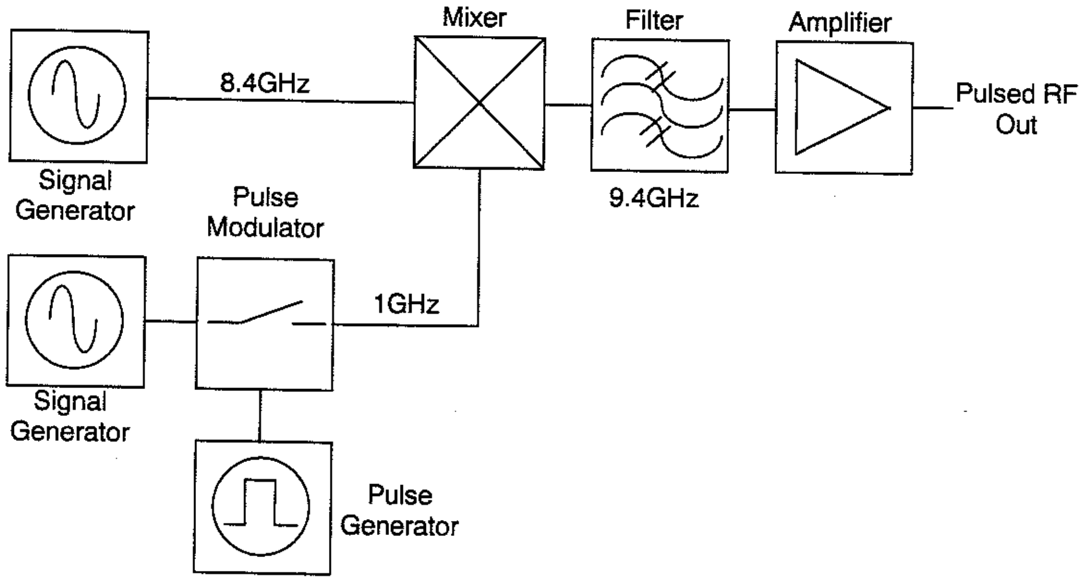


Figure 9 Pulsed RF Source

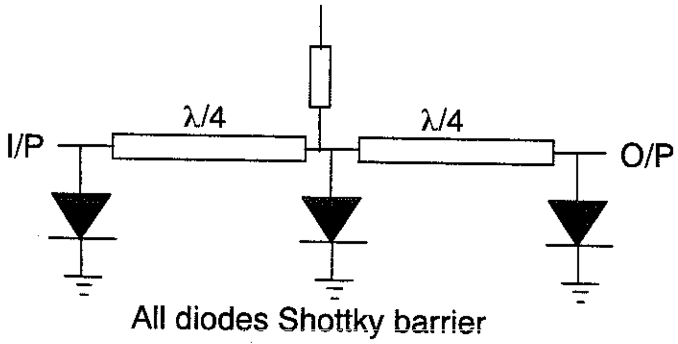


Figure 10 Pulse Modulator

From our experience of drain modulated FET amplifiers it was felt that it should be possible to produce a pulse modulator with adequate on / off ratio working at signal frequency, which would not introduce significant AM to PM distortion onto the signal at the time the measurements were being made.
The modulator consisted of a cascade of low gain amplifiers operating at saturation current, with the FET gates at 0V. Under these conditions the isolation when in the off state is maximised and the FETs settle within 10ns of the drain voltage being applied. Settling time of the output pulse was found to depend upon the settling time of the drain modulator circuit. Video feed through from the pulsed drain voltage into the gate circuit was minimised by the use of short circuit quarter wavelength stubs in the gate circuit. By making these stubs resonant at 3GHz, it was possible to make a modulator which was suitable for use on both S and X bands. Figure 11 shows the spectrum of a pulse modulated signal using the FET modulator, and figure 12 shows the racons response.

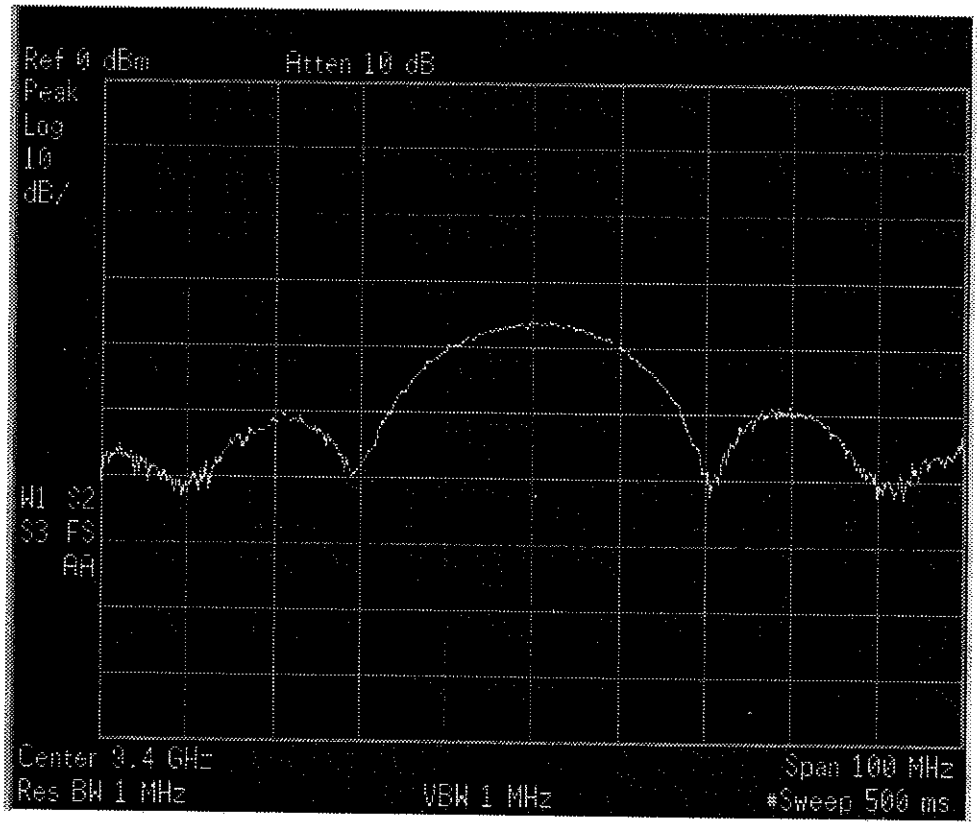


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Figure 11 Pulse Spectrum of FET Modulator

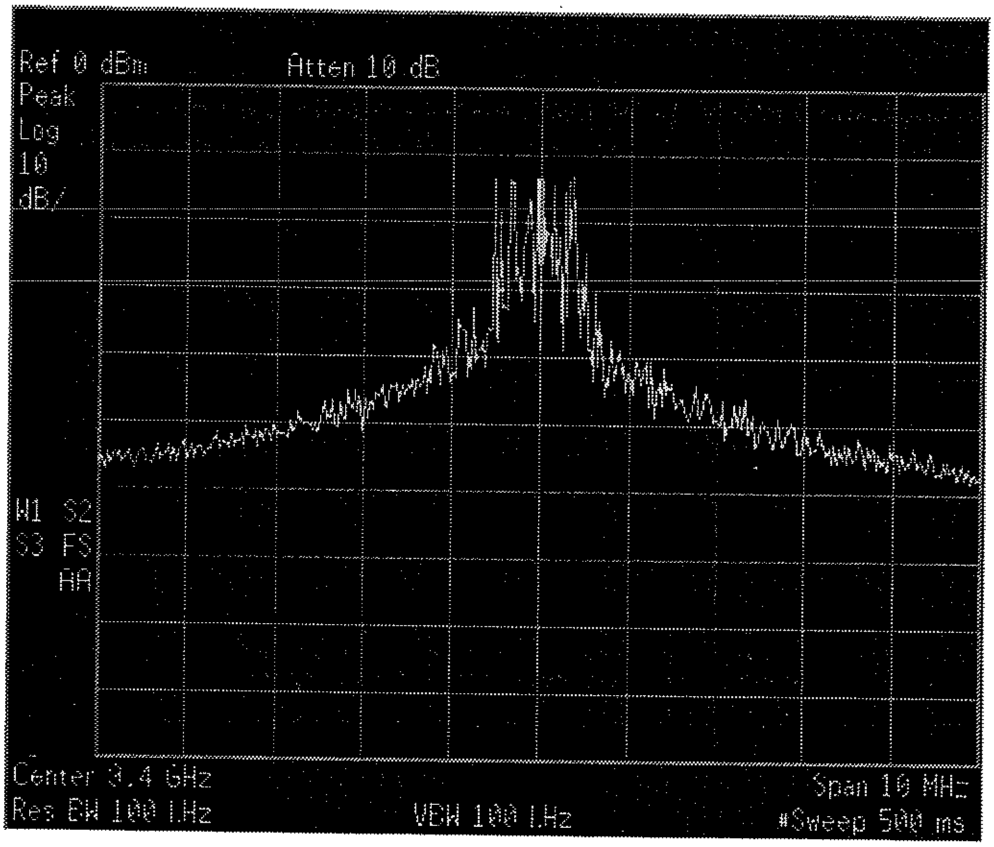

Figure 12 Racon Response to The Output of the FET Modulator

Another signal generator induced effect was noticed when measuring the racons response delay time. The test equipment configuration was as shown in figure 13.

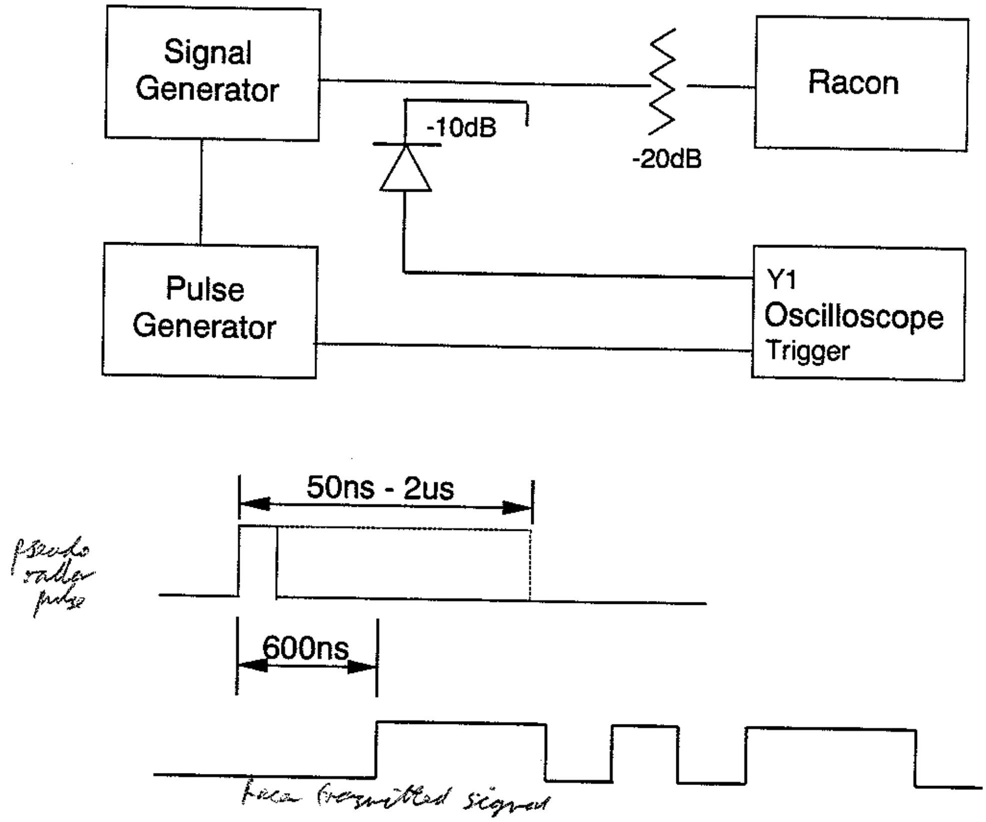

Figure 13 Racon Response Timing Measurement

This is far from an ideal configuration, but was made using components to hand at the time. The requirement is to measure the response delay as the input level is varied over as much of the dynamic range as possible. This requires that the attenuation between the signal generator and racon be as low as possible, but high enough to prevent any damage to the signal generator from the racon transmitter. Ideally an isolator would be placed at the signal generator output, but these are not ' off the shelf ' items, and no suitable device was available at the time. Also as our experience was to prove, a single isolator, typically giving the same reverse isolation as the 20dB pad would not have been adequate. Using the same detector for the interrogating pulse and reply pulse allows both pulses to be shown on the same trace with no differential delay errors. A disadvantage is that the indicated level of the transmitted pulse is dependent on the reverse coupling of the directional coupler, which is where the problems started to occur. It was noticed that the transmitter power appeared to be varying wildly on a pulse to pulse basis when the interrogating pulse from the signal generator and the transmission from the racon overlapped. Under these conditions the signal generator output level also became erratic causing the racon to interpret some of the pulses as coming from an antenna sidelobe and then inhibiting the response. By using a second coupler and detector, this time aligned to indicate forward transmitter power we were able to show that the transmitter was not at fault, and that the indicated transmitter power level changes were caused by changes in the VSWR at the signal generator output. If the signal generator's output levelling circuit were being gated to allow the control of short pulses, this would explain why erratic operation was only seen when the two pulses overlapped.

Since in this case only timing information was required for design-proving, the erratic operation could be tolerated. In more demanding circumstances a much more elaborate test configuration ensuring adequate isolation between the signal generator, and the signals generated by the unit under test would required. Particularly if the signal generator in use had reverse power protection

Conclusion

Modern test equipment performs to a very high standard, it is however designed to meet the requirements of the majority of users. These users do not require perfection in all parameters simultaneously, and the extra cost of providing facilities that would only be required by a very small minority of users cannot be justified. When making measurements which could be considered in any way specialised it is necessary to check that the test instruments being used can deliver the performance required in all parameters, and that any responses produced by the unit under test will not cause any unexpected side effects. It may be necessary to become a test equipment designer in order to prove the performance of your latest creation.

Acknowledgements

I would like to thank Pharos Marine, for whom the racon was developed, for permission to publicise this information; and to acknowledge the contribution made by Paul Brooking who designed most of the circuitry in the racon and the special to type test equipment described here which was used to verify its performance.