A Frequency Standard for the Radio Amateur

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Introduction

At the 12 Ghz conference in Dorsten [1] a measurement aid for the calibration of frequency counters was presented. An accuracy of around 2*10-9 was achievable using signals from a TV transmitter. [The implication here is that it is the RF carrier frequency of the transmission that is used]. Already at the meeting it was frequently asked, why not use DCF77 - that way the expense [of the equipment] would be significantly lower?

In principle it is possible to synchronise a crystal oscillator using DCF77. However, the authors of various publications have not considered all the possibilities offered by DCF77 signal. They therefore easily overlook that not only is the wanted frequency present, but also the seconds information (AM) as well as a pseudo random inversion of the carrier phase (BPSK) which is used to carry the time information. On reflection, the necessary circuit design [to handle these signals] becomes very expensive. Most commonly, the time constant of the PLL is far too short, which is easily observed by monitoring harmonics of the synchronised crystal oscillator. Up to date information about DCF77 is available from the Physikalisch Technischen Bundesanstalt (PTB) [probably analogous to our National Physical Laboratory] in Braunschweig.

Thanks to Dr Peter Hetzel, of the PTB, from whom I received a pre-print "Zeitinformationen und Normalfrequenz" from Telekom-Praxis 1/93. In this pre-print it was fully explained, among other things, why the carrier is reduced to zero for 250us with every seconds keying, and only afterwards reaches the rest value. After this it will be clear to most people how this has implications for some of the 'simple synchronisation circuits'.

From two articles [2] "Frequency Standards from the baseband ZDF [ZDF is a German TV station analogous to our BBC1] signal" by Dr Peter Hetzel as well as "Pulse system of the ZDF for synchronising the studio centre" by Günther König I appreciated for the first time the precision of the ZDF signals and the resulting possibilities.

In the ZDF synchronisation centre at Mainz there is an atomic Rubidium frequency standard which is locked to the DCF77 Time and frequency standard transmission. From this the video signals are generated with a frequency stability of less than $1*10^{-11}$ and the accuracy is recorded in the weekly periodical "PTB time service bulletin". Here a daily measurement of the difference between seconds impulses of the UTC time scale and the next video synchronising pulse as received in Braunschweig from the Uelzen transmitter. These deviations are however not relevant for further consideration here.

In the former DDR the distribution of frequency standards through stabilised TV sync pulses played an important role in the provision of time and frequency standards. As a result of the good results with this method, and to secure the continuity of supply of frequency reference distribution after the unification of Germany, the PTB and it's DDR counterpart (ASMW) approached the ZDF to see if this process could be continued after the cessation of DDR-TV. ZDF was chosen because it had the prerequisites of the centralised structure and associated technology as well as European availability via ASTRA. At the synchronisation source of the ZDF only one signal generator needed changing and the already DCF-77 locked Rubidium source was readjusted. Through the co-operation of the ZDF since Spring 1991 the video sync pulses of the ZDF have been referenced to the PTB frequency standard, and the ZDF signal can be used as a reference signal for the calibration of local frequency standards.

Not only the sync pulses are referenced to the rubidium standard - also the colour sub-carrier has a higher precision. It should have an accuracy of better than 4.43361875 MHz +/-1 Hz according to the CCIR standard.

For reception either a standard TV receiver or an ASTRA receiver with a baseband video output can be used.

What is a Video signal?

For a short introduction to video signals Bild1 shows the timing of the vertical sync pulse. A full picture lasts 40ms and contains 625 lines each 64us long. In Bild 2 a line sync pulse is shown.

In Bild 1 in the expanded view one can see pulses with a duration of 32us, the so-called equalising pulses. These are necessary for TV receivers to keep the horizontal oscillator synchronised during the vertical sync pulse, so that at the top of the picture the phase locked loop of the line oscillator is still in lock.

In Bild 2 one can see a complete line. Preceding the sync pulse id the 'front porch' of 1.5us black level. After the sync pulse the back porch of 5.8us can be seen, the sync pulse itself lasts 4.7us, so for the visible active line period only around 52us remains. Just before the end of the back porch can be seen the colour burst of the PAL system. These explanations are necessary to understand the operation of the associated circuit description.

The peak to peak amplitude of such a baseband signal is normally 1Vp-p into 75 ohms, however with older ASTRA receivers it is possible that this is only 700mv p-p and a suitable amplifier stage should be used to bring the signal up to standard level. From this composite video signal the sync pulses must be extracted for further processing.

Circuit description

Bild 3 shows the block diagram. The composite video signal from the TV or ASTRA receiver is connected to the FBAS-Eingang [video input]. With J1 a high-impedance or 75ohm match can be selected. In a comparator the sync pulses are separated from the video information. The input level should be at least 1Vp-p - although only the amplitude of the sync pulses is important for the comparator (LM1881). The sync pulses are normally 300mV, and should be at least 270mV otherwise they may not be correctly detected. The other outputs of the LM1881 are not required for this application.

The subsequent retriggerable monostable switches the loop filter into circuit and lights the LED if there is a video signal present. With no input signal a DC level is switched into circuit so that the oscillator can be adjusted to its nominal frequency in the unlocked state.

A non-retriggerable monostable removes the equalising pulses so that only the 15.625 kHz frequency without equalising pulses is present at the phase detector (4046).

The crystal oscillator uses a standard configuration with a 74HC00. The oscillator signal is taken via a HC00 gate to the output and another gate section to the divider chain. To derive 15.625kHz from 10Mhz a divide by 640 circuit is needed. This divider is implemented in the current design using a programmable gate array - in this way all crystal frequencies which can be integer divided to 15.625 kHz may be programmed in. The loop filter for the PLL is designed so that the PLL does not lose lock for short disturbances to the video signal - the time constant is approximately 20 seconds.

Bild 4 shows the circuit diagram. Since the individual blocks are identical to those in the block diagram, no further explanation is necessary. The circuit shown in Bild 4 and the corresponding overlays in Bild 5 and 6 show the construction of the board. The board measurements are 53 x 72 mm, so that the circuit can be soldered in a suitable tin box, with suitable connectors, BNC or otherwise as the constructor prefers. A power supply of 9 to 18V DC suffices, since there is an on-board 5V regulator.

References

see original text

Complete assemblies are available from EISCH-electronic in 89079 Ulm-Gögglingen. The author has made no agreements regarding any alternative sourced boards!

I have spoken to several UK suppliers about sourcing the units in the UK , but at present it may be better to obtain your unit direct from Germany. The current cost is approximately 120Dm, but please enquire first before sending money.There is a small addition for credit card sales in Germany, in general.

73 de Sam

WARNING!

There is a danger with older TV sets, that the chassis may be at mains potential!

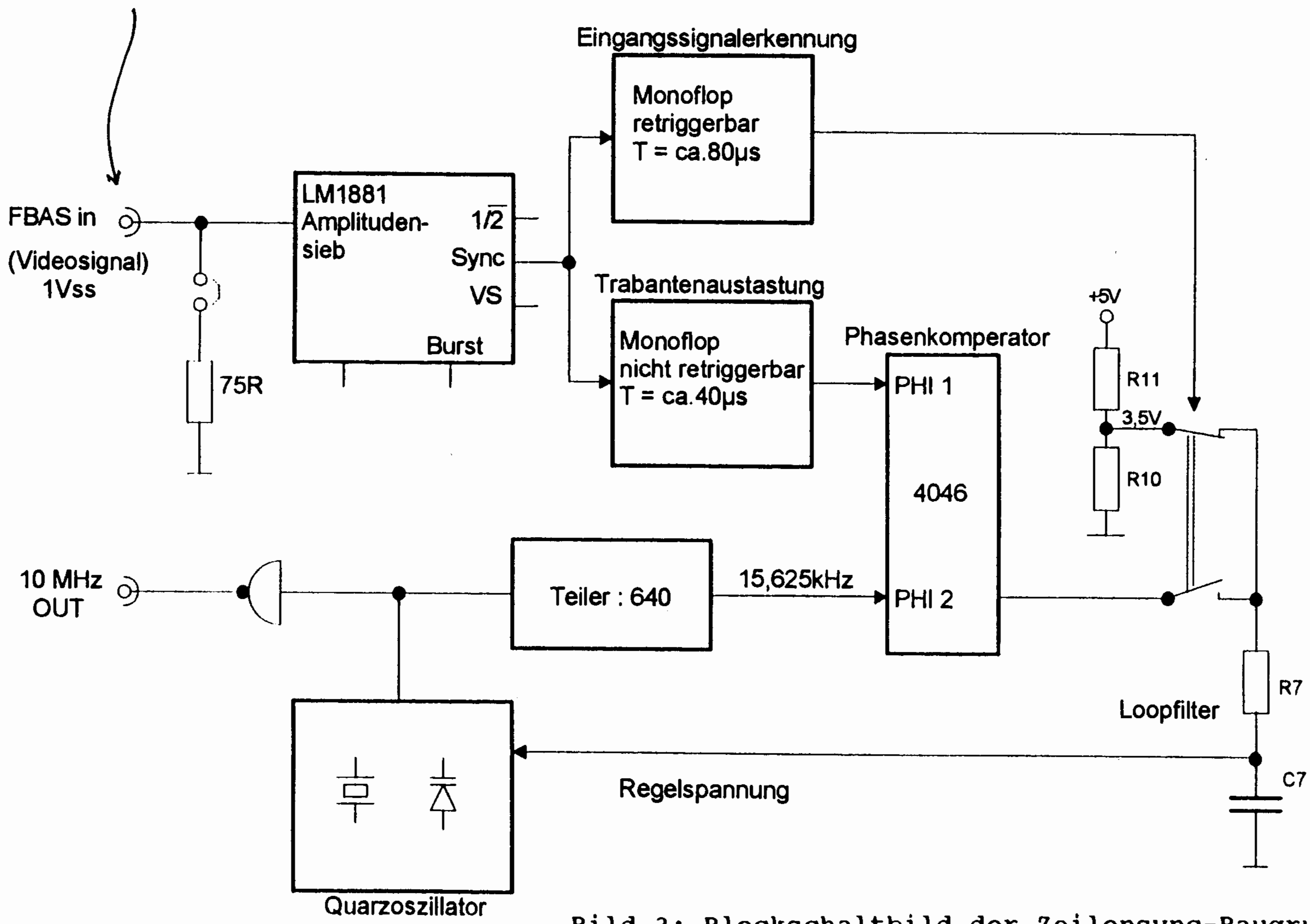


Bild 3: Blockschaltbild der Zeilensync-Baugruppe

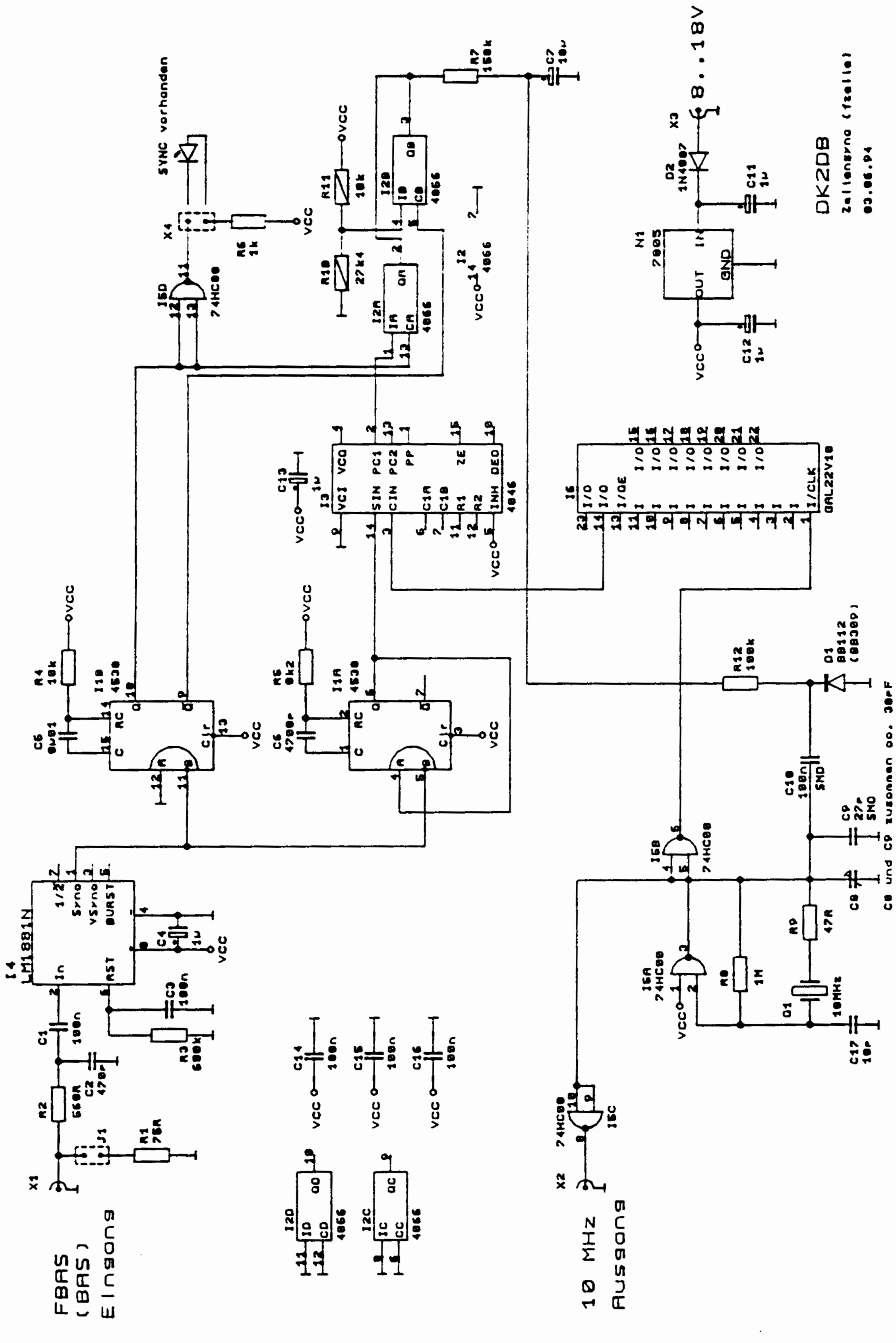


Bild 4: Schaltbild der Zeilensync-Baugruppe

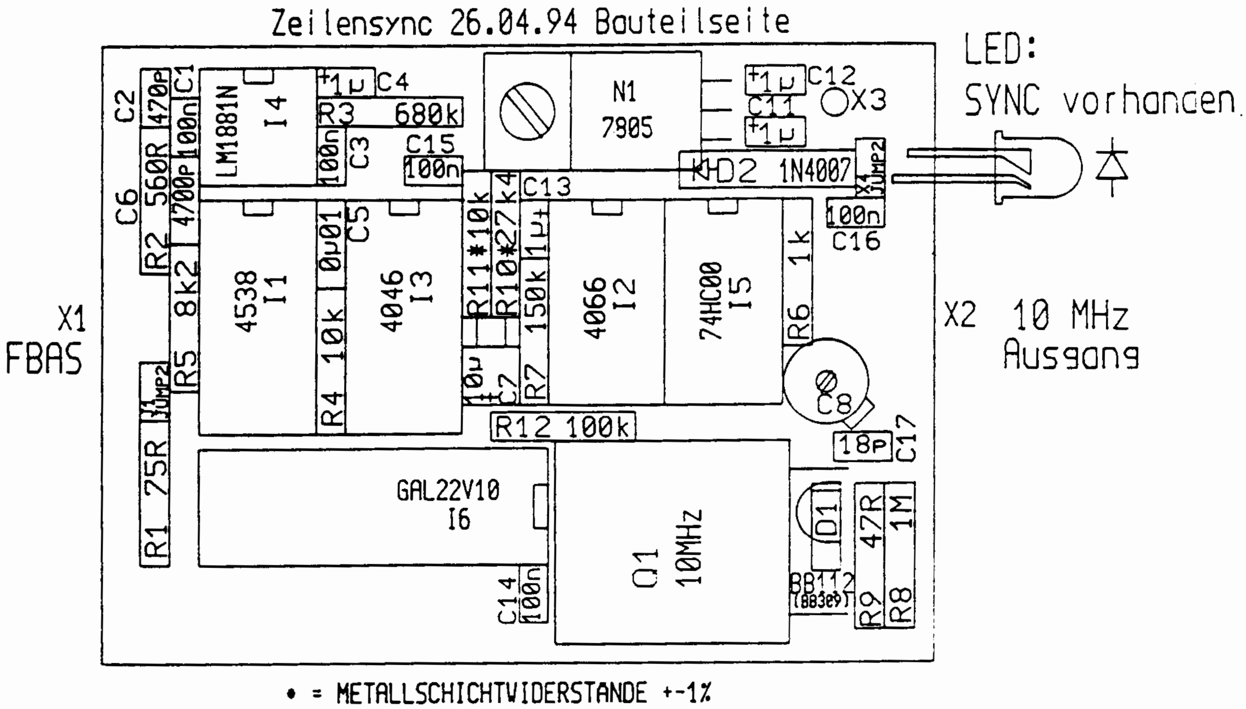
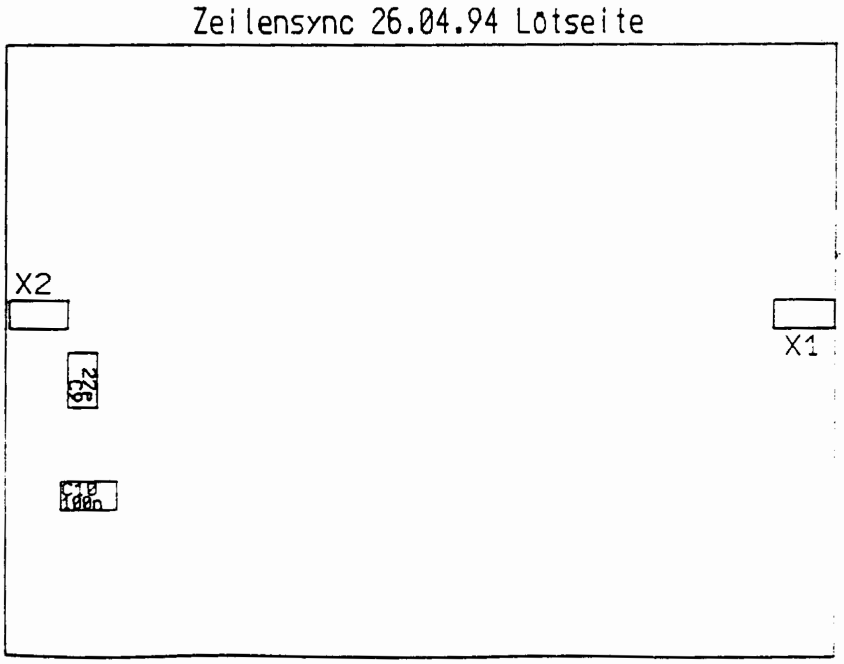


Bild 5: Bestückungsplan (Bauteileseite)



Ein- und Ausgang im Weißblechgehäuse
mit BNC (bzw. je nach Wunsch)

Bild 6: Bestückungsplan (Lötseite)

Modifications to the MSF frequency reference
by A C Talbot G4JNT

After continuous use of the MSF based frequency reference published in Radio Communication, April and May 1994, together with comments by others in RadCom August 1994 and the Microwave Newsletter May 1995, I have made a number of modifications to improve the stability of the output signal when multiplied to microwave frequencies.

The main changes are in the area of the phase locked loop; the time constants are made significantly longer in order to reduce the random short term frequency changes caused by shifts in phase of the received signal.Referring to figure 4 in the original article,the values of R1 and R2 are changed to 120k and 27k respectively. This results in a loop bandwidth of around 0.02 Hz and means that the rapid changes in tone of several hundred Hz when listening to the signal multiplied to 10 GHz are considerably reduced.

However, the reduced bandwidth means that the initial crystal frequency at turn on must be correspondlingly closer to the centre frequency to be inside the loop capture range and allow lockup. If, as a rule of thumb, a value of half the loop bandwidth is taken, then divided down crystal frequency must be within 0.01 Hz of nominal to achieve a valid lock; this corresponds to less than 0.2 parts per million! The most straightforward way to achieve this is merely to tweak the VCXO trimmer capacitor each time the unit is turned on whilst observing the phase meter. When adjusted accurately, lock up can usually be achieved in less than two beats which should occur within a couple of minutes; a greater initial error causing correspondingly greater time to lock. Once locked, much wider frequency excursions caused by temperature can then be tracked.

To aid locking and tracking, a crystal heater can be added. The basic PTC ones supplied by the Microwave Components Service are adequate for this but the warm up time adds about another two minutes to the start up time. To obtain a signal stable enough for multiplication to 10 GHz and beyond, the loop then needs to be left for about another 10 - 20 minutes for full stability to be achieved. Before adding a crystal heater, my loop once lost lock when sunlight suddenly appeared and quickly warmed the unit faster than the loop could compensate for it.

Since the lock up procedure is now so much more involved, the best solution is to leave the reference running continuously. Accordingly battery back up should really be added to allow continued stability throughout power cuts (very common where I live in a modern urban area using aluminium undergroundcables, but that's another story!).

Another change that helps stability, especially from a battery supply, is to run the OP-amp in the loop off the 5V stabilised supply rather than the 12V as shown in the original article. (Contrary to some opinions, this was not an error as I originally thought the wider voltage swing would be necessary). To obtain the maximum possible output voltage swing and hence locking and tracking range, this OP-amp should be replaced with one of the more modern FET devices such as the LF351 whose output can swing closer to the supply rails.

To assist operation over wide operating temperatures, it is useful to be able to switch the front panel meter to monitor loop control voltage. Once locked up, monitoring the loop phase is uninspiring, but observing how the VCXO tuning voltage alters during the day as temperature changes can be quite enlightening - if nothing else it shows how PTC crystal heaters do not maintain a completely accurate temperature setting. Use the OP-amp output pin rather than the VCXO feed after the 1 Hz filter to avoid loading the signal by the meter resistance. A few microvolts here can shift the frequency noticably.

A lot of available test equipment allows the option of a 5 or 10 MHz input reference which is not currently available from the MSF unit. I am working on a Mark II version which will be based around an ovenned 10 MHz VCXO. Derivation of the 60 kHz signal to lock to MSF will be more complex but this can be derived by using a X3 stage in the divider circuitry. The most likely line up will be 10 MHz (10 = 1 MHz, X3 = 3 MHz, /50 = 60kHz). With the much narrower loop bandwidth now achievable, it should be possible to dispense with the tone decoder and gating circuitry. A phase locked loop with a bandwidth sufficiently narrow can remove all the carrier breaks without even blinking. Details will follow before too long.....

I have been comparing a 1 MHz signal derived from the MSF unit (with the new loop time constants) against very stable Rubidium and Caesium sources; the results are somewhat disturbing but are really no more than expected. During the daytime, when interference is not present, short term stability measured over several minutes can be better than 10^-9 but random changes are always observed, generally at rates corresponding to the loop time constants. At night, and especially at dusk and dawn, phase shifts at 1 MHz corresponding to frequency errors of 5 x 10^8 are common (this is equivalent to 500 Hz at 10 GHz and is very audible). Interference such as that from nearby computers and car ignition noise can have a similar effect in the short term during the day.

I would be please to receive any feedback from constructors of my design.

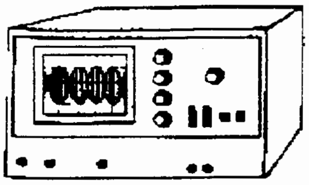
(MANY THANKS, ANDY, FOR YET ANOTHER VERY STIMULATING ARTICLE...editors)

A postscript:

I've made the time constants longer still; changed R1 to 1M , R2 stays at 27k. Once locked, after carefully tweaking to centre frequency, the note, when multiplied to 10 GHz actually sounds clean. Don't know about locktime - I left it 30 mins before trying to measure anything.

Switching between 108 MHz from MSF reference and 108MHz derived from an Rb source multiplied up sounds the same (to a non musical ear anyway).

73 Andy



OFF-AIR FREQUENCY STANDARDS

....some thoughts and notes by Steve, G4LRT

These comments are aimed at adding to the growing interest in accurate frequency measurement at microwave frequencies. The writer recently built the TV-locked frequency source described in the January 1996 issue of this Newsletter.

The LM1881 chip (see January article) is available from Maplin at the current catalogue price of £4.59,. not at £5.99 as quoted in the article. However there are a couple of alternative means of obtaining the line sync from the video signal as figures 1 and 2 below show. Figure 2 perhaps is as simple as you can get!

Fig.1 (afterG4YPB...CQTV magazine no. 130)

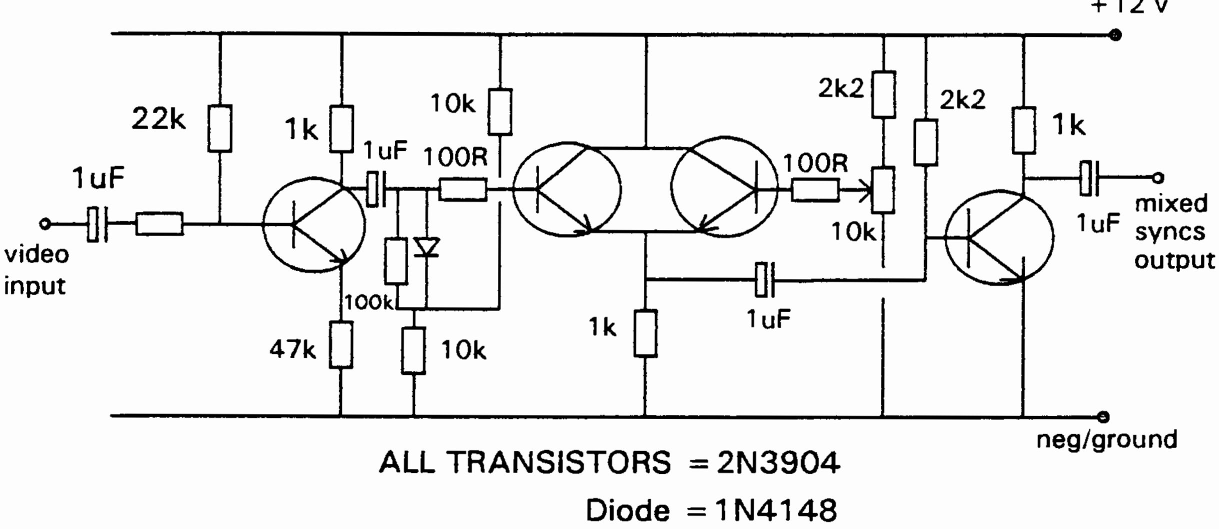
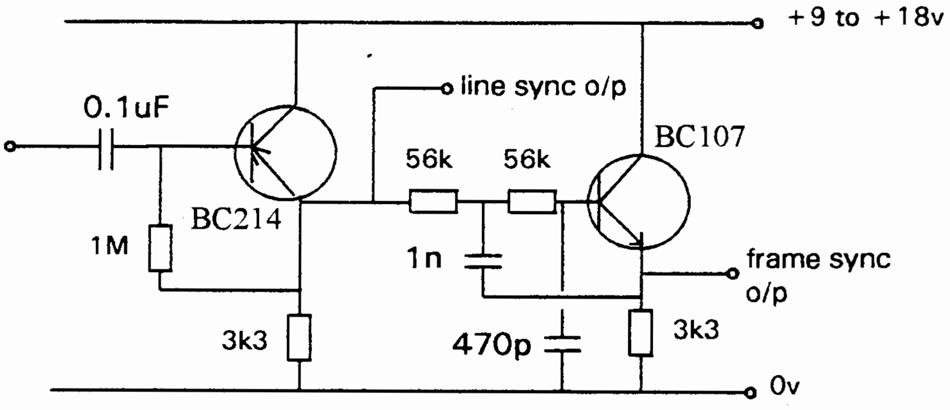


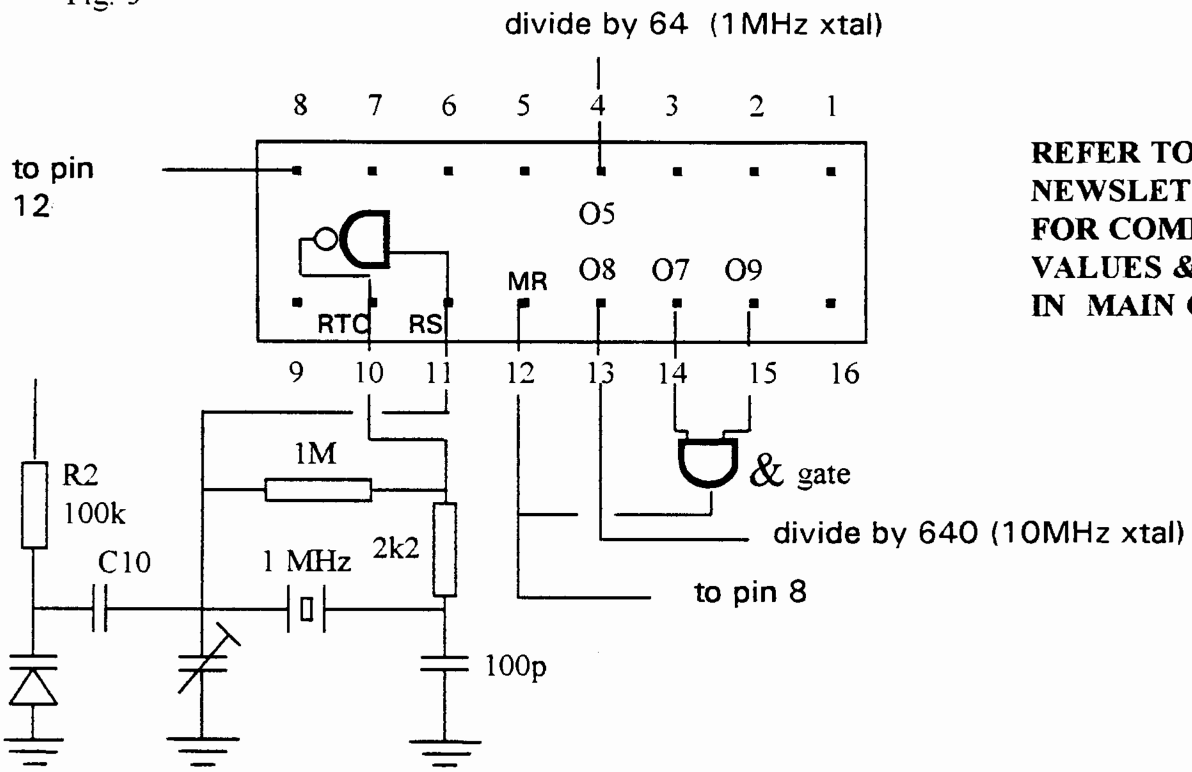
Fig.2 (after G8MNY..CQTV magazine no.158)



Note: In the above case (fig.2) only the first stage is really required.

The programmable logic device shown in the January article is not required of course and a 4060 14 stage divider is used instead. This also has a built-in oscillator circuit. The following diagram (figure 3) is based on the data sheet for the device and uses a 1MHz crystal. A 10MHz crystal has not been tried but would divide by 640 at pin 13.

Fig. 3



REFER TO JANUARY NEWSLETTER ARTICLE FOR COMPONENT VALUES & LOCATION IN MAIN CIRCUIT

Standard resistors can be used for R10 and R11. C10 can be a stanard type disc ceramic. If divided by 640, the divided waveform will not be 1:1 mark/space ratio so it will be necessary to use pin 13 of the 4046 (see January's article) as a DC error output since this output works on edge detection.

By the way the 4538, shown in January's article, is available from Mainline Electronics. A 4098 is pin-compatible with the 4538 and is available from Maplin.

A FERRITE ANTENNA FOR THE JNT MSF-LOCKED SOURCE

G4LRT's notes detail a paper design for an MSF-locked source somewhat on the lines of the G4JNT design as described in the April 1994 and May 1994 issues of RadCom. While there are some interesting deviations from Andy's circuit we do not, at this stage, include the full G4LRT version. However, Steve makes an interesting observation regarding the ferrite rod antenna used to receive the 60kHz MSF signal. Steve's antenna employs a **150mm** length of ferrite rod, some **18 to 20mm thick**! This has a **main winding** of **300 turns** of thin enameled copper wire with a **paralled 1500pF** polystyrene capacitor. A **30 turn link** winding is wound over the centre of this coil and is connected via a length of thin coax to a straight forward BC109 -- BC109 -- NE567 (PLL) receiver which appears to be part of the main frequency standard pcb. This is unlike the G4JNT unit where the 60kHz receiver is remote from the PLL, its supplies and 60kHz output sharing a common coaxial downlead of some 1 to 2 metres length. The G4LRT antenna is set up on an oscilloscope by placing a single turn loop, with a series 50 ohm resistor, over the end of the rod. The tuning capacitor is then carefully adjusted for maximum indicated signal. **It will tune very sharply. The antenna exhibits sharp resonance coupled with a broad beam width. If a rod with small width/multi layer coils is used** (as one might obtain as a ready made item from Maplin for example) **the bandwidth will be large and beamwidth small** and therefore not as suitable as the single layer type for this application.

Many thanks Steve for the interesting observations....editors